CONTRIBUTIONS

TO THE

CENTENNIAL EXHIBITION.

BY

JOHN ERICSSON.

Introduction

This facsimile edition is an exact copy of a book published in 1876 by the Swedish inventor John Ericsson.

The book was written for the World Exhibition held in Philadelphia in celebration of the Centennial of the Declaration of Independence. The purpose of the exhibition was to show the progress of developments in various fields. However, John Ericsson was not invited. In order to fill what he saw as "a gap of more than 30 years", he wrote a short summary of his most important inventions during his years in the United States entitled "Contributions to the Centennial Exhibition". Later on, his little book was expanded into a complete catalogue of 570 pages.

John Ericsson had left Europe in 1839, at the age of 36. In his second home, the United States, he immediately attracted much attention with the "Princeton", the first screw-propelled warship, faster than the great paddle-steamers of those days.

This success started Ericsson on the way to fame. He confirmed his position by building the armoured turret gunboat "Monitor", which resisted the terrible "Merrimac" at Hampton Roads in 1862, an event of decisive importance in the Civil War. As an inventor, he mastered many technical problems, and his success, technically and mostly also economically, was great.

"Contributions to the Centennial Exhibition" is a "list of qualifications" written by a proud and successful inventor. Moreover, it is an invaluable technical document.

This facsimile edition was reproduced from a copy of the first edition held by the Sjögren Library of the Royal Swedish Academy of Engineering Sciences. It contains the author's personal dedication to his Royal Highness Prince Oscar —later Oscar Bernadotte af Wisborg, a brother of the late King Gustav V.

On the occasion of the two hundredth anniversary of the Declaration of Independence, the Academy honours the memory of a great inventor with this edition.

Publication of the book was made possible through the generous support of the Axel and Margaret Ax:son Johnson Foundation.

Stockholm, March 15, 1976

Gunnar Hambraeus

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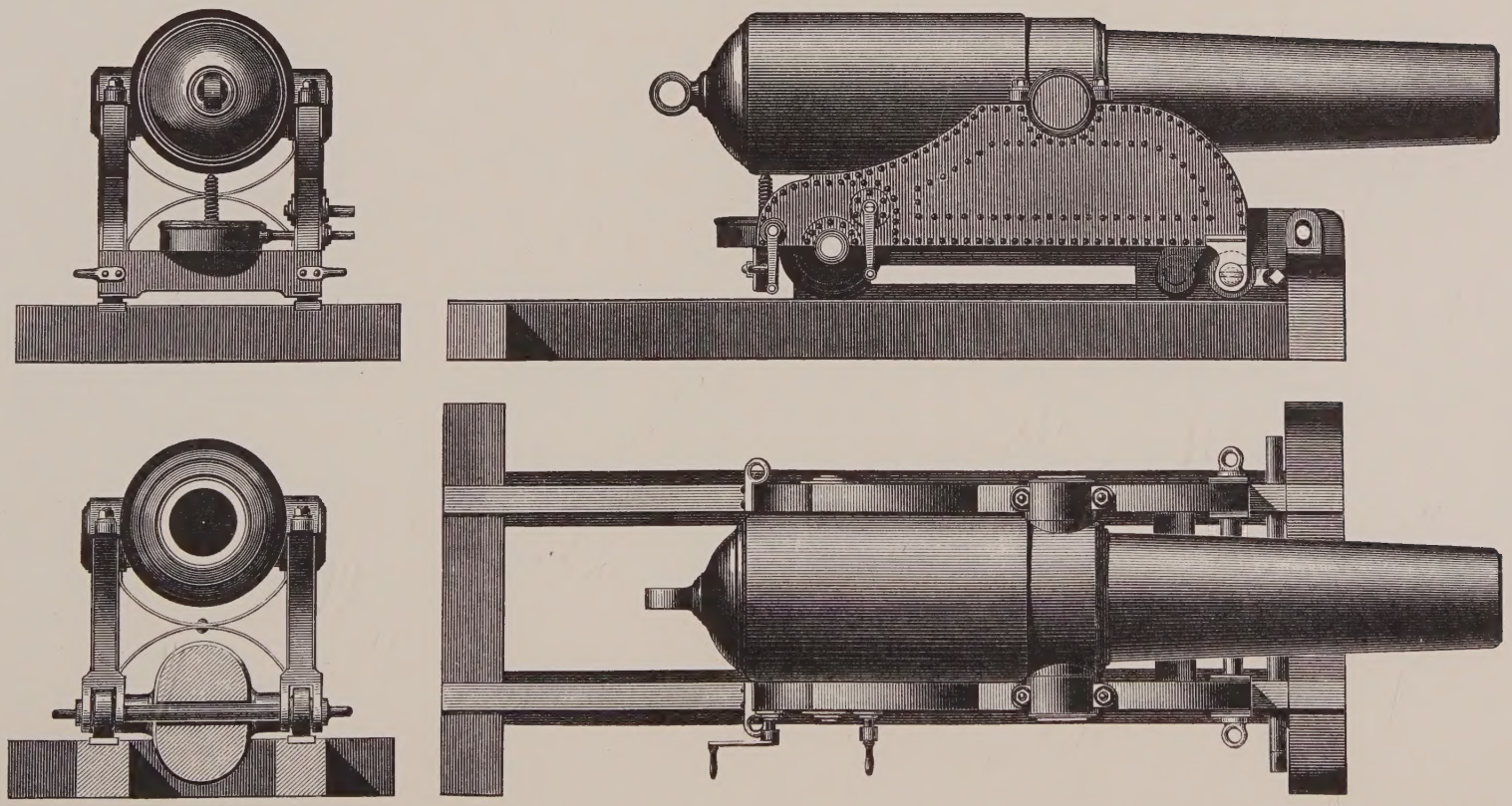
His Royal Highness Prince Oscar

with the author's profound esteem.

TWELVE-INCH WROUGHT-IRON GUN AND CARRIAGE.

DESIGNED BY JOHN ERICSSON.

MOUNTED ON BOARD THE SCREW-STEAMSHIP PRINCETON IN 1843.



CONTRIBUTIONS

TO THE

CENTENNIAL EXHIBITION.

BY

JOHN ERICSSON, LL.D.,

HONORARY DOCTOR OF PHILOSOPHY OF THE ROYAL UNIVERSITY OF LUND; MEMBER OF THE ROYAL ACADEMY OF SCIENCES, STOCKHOLM; MEMBER OF THE ROYAL ACADEMY OF MILITARY SCIENCES OF SWEDEN, AND MEMBER OF VARIOUS SCIENTIFIC INSTITUTIONS IN EUROPE AND AMERICA;
KNIGHT COMMANDER, WITH THE GRAND CROSS, OF THE ORDER OF NORDSTJERNAN; KNIGHT COMMANDER OF THE ORDERS OF DANNEBROG, FIRST CLASS; ISABEL LA CATOLICA, AND SANCT OLAF; KNIGHT OF THE ORDER OF VASA.

NEW YORK:
PRINTED BY JOHN ROSS & CO.

1876.

THE CENTENNIAL EXHIBITION.

THE Managers of the Centennial Exhibition having inadvertently omitted to invite me to exhibit the result of my labors connected with mechanics and physics, a partial gap in their record of material progress exceeding one-third of a century has been occasioned. I therefore deem it proper to publish the following abridged statement of work performed during the last third of the century, the achievements of which the promoters of the Centennial Exhibition have called upon the civilized world to recognize.*

THE PRINCETON.

In the sixty-sixth year of the American Republic—1842—the first steam ship-of-war provided with a submerged propeller and steam machinery located below water-line was built at Philadelphia. Complete success attended this undertaking, as will be seen from the following extract from a speech delivered in the Senate of the United States by Senator Mallory, of Florida, May 14, 1858:

* A complete statement, accompanied by eighty illustrations, will be presented to the principal scientific institutions and libraries in Europe and America, in the course of next winter.

"In 1839 Congress authorized the construction of three war-ships. In 1840 the Secretary of the Navy, in obedience to that law, ordered two to be constructed. There were two plans at that time. The question of whether steam could or could not be successfully applied to war-vessels had not then been solved; the fear of danger from ignition by fire prevailed in the minds of all naval men, and the problem was to be solved. Its solution was demanded by every naval power on earth. One of the officers of our navy, Captain William Hunter, submitted a plan by which wheels were to be inserted in the bilge of the vessel on each side—submerged wheels. Ericsson had demonstrated his plan to be feasible, practicable, and just, already. This was no experiment in the *Princeton.* The experiment had been made at great cost by Captain Ericsson. . . . The Secretary of the Navy, in authorizing the construction of these two vessels, directed one to be constructed on Hunter's plan—not model, as the Senator from Michigan says; the model was not in question at all; our models were as good then as they are now; but the point was the application of steam to naval purposes. One was to be built on Ericsson's plan, and one on Hunter's plan. Hunter's plan proved a total failure. Ericsson's plan laid the foundation of the present steam marine. She was the first war propeller ever built on the face of the earth. In the *Princeton* he brought forward not only his propeller invented by himself, but a great many appliances appurtenant to steam navigation which have since been used in our service.

"Now, to show the estimate in which this ship was held, I will mention that the American Institute, hearing of it, sent a committee to investigate the condition and success of what

they deemed an experiment. I will not read the whole report of the committee of the American Institute. My purpose here is to show the value of Captain Ericsson's services to our country. The committee conclude by saying, after summing up the speed of thirteen knots:

"'In conclusion, your committee beg leave to present the *Princeton* as every way worthy of the highest honors of this Institute. She is a sublime conception, most successfully realized, an effort of genius skilfully executed, a grand unique combination, honorable to the country as creditable to all engaged upon her.'

"This is signed by ten members of the Institute. Further to illustrate: Captain Stockton, in 1844, after describing the ship, her guns and her armament, says everything human language can to extol her in the eyes of the American people. As I said, the *Princeton* is the foundation of our present steam marine. It is the foundation of the steam marine of the whole world. She created universal surprise wherever she was seen. She revolutionized naval vessels; and hereafter, in maritime war, those who send sailing vessels to sea send them but to be captured."

The following extract from the work on "Naval and Mail Steamers," published 1853 by Charles B. Stuart, Engineer-in-Chief of the United States Navy, furnishes some important particulars relating to the *Princeton:*

"This vessel was designed by, and constructed under the superintendence of, Captain John Ericsson, of New York.

HULL.

Length on deck, ...	164 feet.
Length between perpendiculars, . . .	156 "

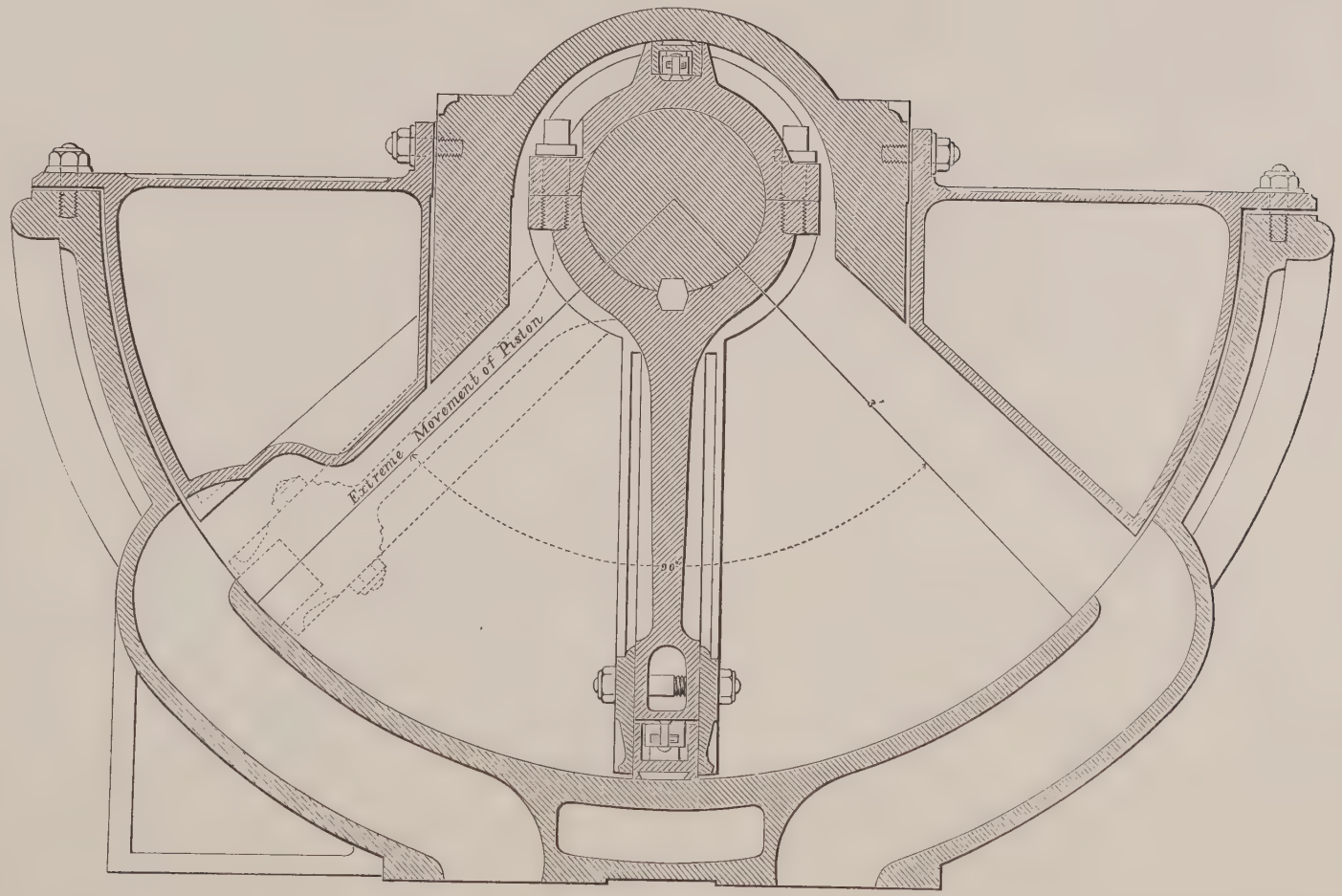
Extreme beam on deck, ...	30 feet 6 inches.
Depth of lower hold to berth-deck, . .	14 "
Depth from berth to spar deck, . .	7 " 6 "
Total depth of vessel, ...	21 " 6 "
Measurement burthen, ...	673 tons.
Launching weight of hull, ...	418 "
Displacement at 16½ feet draught, . .	954 "
Displacement at 18 feet draught, . .	1,046 "
Immersed midship section at 16½ feet draught,	346 square feet.
" " " 18 "	390 "
Draught of water at deepest load, with 200 tons of coal on board, ...	19 feet 4 inches.
Draught of water with 100 tons of coal in, after-bunkers and provisions, and water for the crew, half out,	forward, 14¾ feet. aft, 18¼ "
Mean draught of water with half coal out, and all other weights full, . . .	17 feet.

"The peculiarity of model consisted in a very flat floor amidships, with great sharpness forward and excessive leanness aft, the run being remarkably fine, with a great extent of dead-wood terminating in a stern-post of the unusual thickness of twenty-six inches at the centre of the propeller-shaft, but tapering above and below. This dead-wood and stern-post was pierced by a hole thirteen inches diameter for the passage of the propeller-shaft. The stern, measuring from a perpendicular from the aft end of the spar-deck, overhung the stern-post fifteen and one-half feet, and depending from it was a false stern-post leaving a space of six feet, fore and aft, between it and the true stern-post. The propeller (four-

SEMI-CYLINDERS OF THE PRINCETON'S ENGINE.

DESIGNED BY JOHN ERICSSON. BUILT AT PHILADELPHIA 1842.

TRANSVERSE SECTION.



teen feet in diameter, composed of bronze, with six propeller-blades, pitch thirty-five feet) was placed within this space. The false stern-post, or rudder-post, was composed of a wrought-iron bar, covered with half-inch thick copper plate; it was attached at top by brass flanges to a strong oak knee, securely bolted to the counter of the vessel; the lower part of it was attached by similar flanges to a solid oak timber placed as a continuation of the keel beyond the true stern-post; this timber was fourteen inches deep, and securely bolted to the keel and dead-wood. The metallic false stern-post was five and three-eighths inches broad athwart ship, and two feet long fore and aft; the forward part was brought to an acute angle to diminish its resistance to the water, while its after-part was square to receive the attachment of the rudder. The rudder was also composite in its construction, being formed of a wrought-iron frame, the interstices of which were filled in with pieces of five inch thick pine plank, the whole cased over with a copper plate three-sixteenths of an inch thick. The thickness of the rudder athwart ship was the same as that of the false stern-post, viz., five and three-eighths inches.

ENGINES.

"The semi-cylinder engine of the *Princeton* is unquestionably the most remarkable modification of the steam-engine that has ever been carried into successful practice. A vibrating piston of a rectangular form moving in a semi-cylinder is an old mechanical device. Mr. Watt, in his celebrated patent, embraced this plan for transmitting the motive force of steam to machinery. Since his time several engineers have attempted to build engines on this plan, but without success. In common

with Mr. Watt they have adopted the single semi-cylinder with packing against the piston-shaft. Ericsson's plan differs materially from these various attempts, he having introduced double or compound semi-cylinders of different diameters, with double pistons placed in opposite directions on the piston-shaft, both being acted upon by the steam at the same time, their differential force being the effective motive power of the engine. The combination of two such double semi-cylinders, arranged so as to transmit their power in directions nearly rectangular to a crank-pin common to both, also contributes to the complete success of this singular engine.

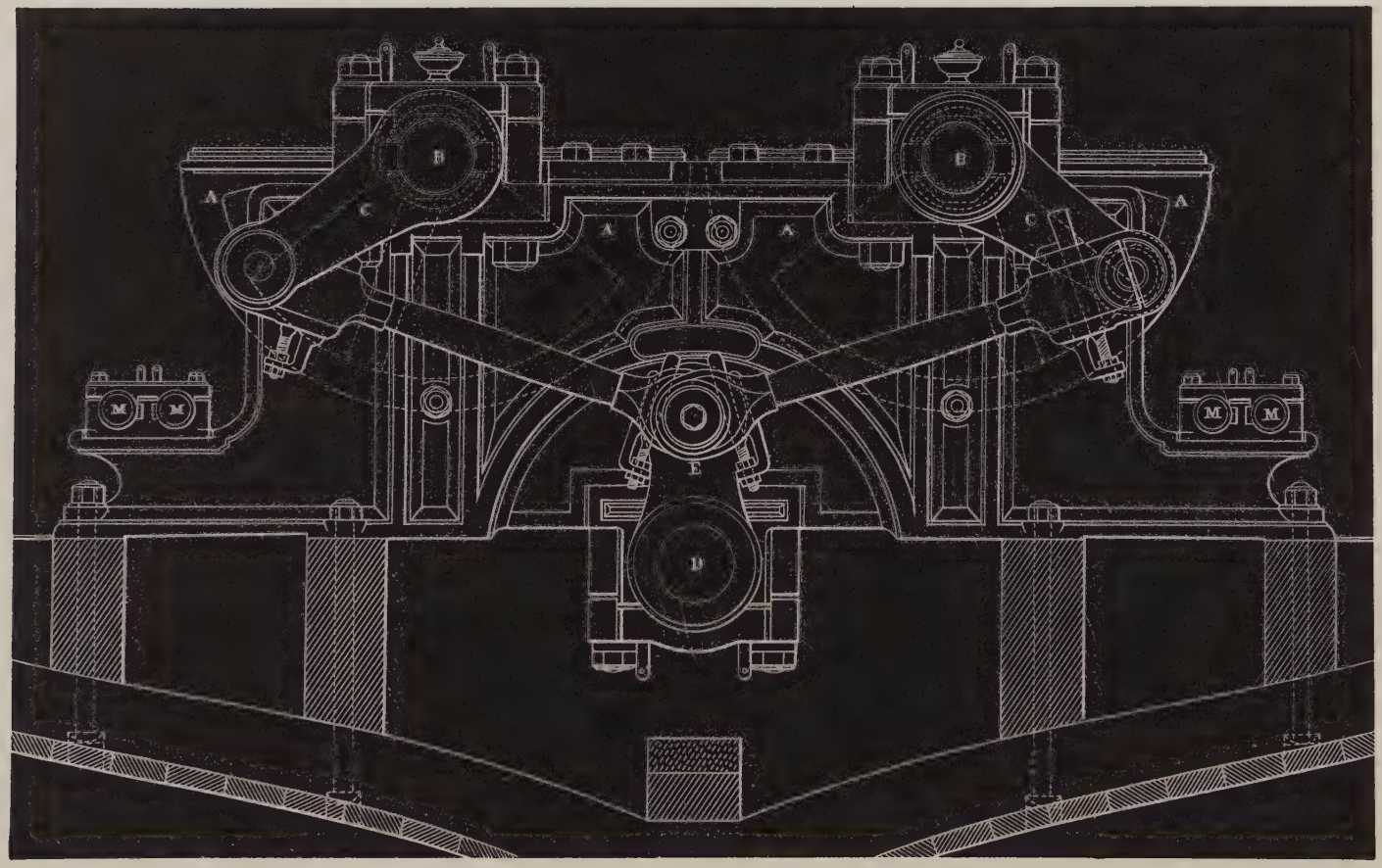
"By reference to the plate, it will be seen that the upper semi-cylinder, which contains the reacting piston, is twenty inches in diameter, the lower or working semi-cylinder being seventy-two inches diameter, both ninety-six inches long in the clear. The radius of the reacting piston, being deducted from that of the working piston, leaving twenty-six inches *effective* width of piston, with its centre of pressure placed $10 + 13 = 23$ inches from the centre of the piston-shaft. The active piston area will thus be $26 \times 96 = 2{,}516$ superficial inches, moving at a mean distance of twenty-three inches from the centre through an arc of ninety degrees.

"On close examination this engine will be found to possess many peculiar properties, some of which merit particular notice. The vibration of the working piston will be found to correspond nearly to the beat of the pendulum, and thus, unlike the ordinary engine, the return movement of the piston at each termination of the stroke is materially assisted by the force of gravity. An undue accumulation of condensed water on the piston, so difficult to carry off in the ordinary engine,

ENGINES OF THE PRINCETON.

DESIGNED BY JOHN ERICSSON. BUILT AT PHILADELPHIA 1842.

FRONT VIEW.



presents no inconvenience here, as the inclined position of the piston allows the condensed water to flow gradually down into the steam-passages before the piston reaches the termination of the stroke. The outward tendency of the packings, induced by centrifugal force, assists materially in forming tight joints, the main packing being held out by the force of gravity. The lateral yielding of the piston-shaft, caused by the pressure of the steam on opening the inlet-valve, tends to give additional tightness to the packings, the pistons being forced into reduced radial limits by the yielding alluded to. The crank-levers attached to the piston-shafts being placed nearly in the same position with the main pistons, it will be found that the crank journals of those shafts are relieved from pressure, on principles analogous to the relieving of water-wheel journals, by transmitting the power at some point near the centre of pressure. The increase of force imparted to the crank-pin at each half turn of the main crank, owing to the angular position of the piston-rod cranks, and happening, as it does, when the former presents short leverage, is a marked feature of this engine.

"The small angular movement (ninety degrees) of the main piston also deserves attention. A greater motion, while it would augment the power of any given-sized cylinder, would cause undue strain on all the principal bearings, as the force of the piston obviously increases in the inverse ratio of the sines of the angles of the piston-shaft cranks, with reference to the position of the connecting-rod. A very moderate increase of diameter makes up the loss consequent on the short arc through which the piston vibrates. Very deep cylinder-covers, giving great strength to resist the upward pressure of

the steam, may also be named as an advantage resulting from the short vibration.

"As an instrument of producing, by *direct means*, the high speed requisite for screw-propellers, this engine commends itself to the engineer. In its fitness for screw-vessels it seems to fulfil every condition. The very limited number of working parts, and the small amount of matter to be kept in motion, are self-evident advantages, best understood by reference to the plate. It is important to notice that the piston-shaft journals are supported by bearings placed *outside* of the heads of the semi-cylinders, and that the brasses admit of adjustment in every direction; the exact position of the centre of the piston-shafts, with relation to the centre of the semi-cylinders, being indicated by an external index, enabling the engineer at all times to keep the shaft in line.

"The main packing is rendered accessible by lifting up one of the covers, and removing the nearest side-plate forming the packing-groove. The upper packing becomes accessible by lifting up the centre piece which forms the upper semi-cylinder. It may be stated with regard to the packings that the *Princeton*, after having served during the war with Mexico, was despatched on a cruise to the Mediterranean without requiring new packings."

Mr. J. O. Sargent, in a lecture on "Steam Navigation and the Arts of Naval Warfare," delivered before the Boston Lyceum in 1844, stated with reference to the motive power of the *Princeton:* "The next peculiarity to be noticed in the *Princeton* is the absence of the ordinary tall smoke-pipe employed to produce the draught for keeping up combustion in the furnaces of the boilers. The smoke-pipe has hitherto formed

a serious objection to a steamer as a ship of war; for the moment it is carried away the efficiency of the engines ceases from want of steam. The draught in the boilers of the *Princeton* is promoted by means of blowers placed in the bottom of the vessel, and is quite independent of the *height* of the smoke-pipe, which is only carried about five feet above the deck of the ship. If this inconsiderable projection should become partially deranged by a shot, the draught kept up by the blowers will continue as efficient as before.

"It is not out of place here to observe that Ericsson was the first to apply to marine engines centrifugal blowers, now so common in this country in all boilers using anthracite coal. In the year 1831 he applied such a blower, worked by a separate small steam-engine, to the steam-packet *Corsair*, of one hundred and twenty horse-power, plying between Liverpool and Belfast."

TWELVE-INCH WROUGHT-IRON GUN AND CARRIAGE.

The question has frequently been asked, When was wrought-iron ordnance first introduced on board ships of war? When was breeching first dispensed with and wrought-iron carriages introduced? The heading of our frontispiece gives an answer to these queries.

Captain Robert F. Stockton, of the United States Navy, on visiting England, 1839, for the purpose of witnessing the trial of a small screw-steamer (the first iron vessel to cross the Atlantic) built for him by Messrs. Laird, to my design, consulted me regarding the possibility of constructing naval ordnance of wrought iron. Being an advocate of that material, I readily met the wishes of Captain Stockton, and at once prepared drawings of a gun of 12-inch calibre. The Mersey Iron Works near Liverpool, being willing to enter into a contract with Captain Stockton, received forthwith an order from that enterprising and spirited officer to build the gun at his expense. Experienced commodores at the time protested loudly against the proposition to mount "the monster gun" on board

a vessel so lightly built as the *Princeton*, insisting that among other difficulties the breeching would tear her upper works to pieces. It was urged by the opponents of my new system that the handling of such guns at sea would prove impossible, the constructing carriages of sufficient strength being pointed out as impracticable; while the imprudence on the part of the Navy Department to intrust such matters to mere engineering skill was severely criticised. In spite of all remonstrance, however, Captain Stockton's influence with the Government prevailed. In the meantime the problem of handling the 12-inch gun received due attention. Calculations of the dynamic equivalent of the recoil convinced me that a moderate resistance, if continuous and uniform, would suffice to bring the piece to rest in less space than that required by breeching. *Friction*, being the simplest means of obtaining a continuous resistance, was accordingly resorted to. The method adopted will be readily comprehended by reference to the illustration already referred to, which represents a side elevation, top view, and end views of the gun, carriage, and slide, mounted on board the *Princeton* in 1843. Two pieces of timber of semi-circular section, placed a few inches apart, slightly taper towards the front end of the slide, are secured to the latter in such a manner as to admit of some vertical motion. A broad hoop of plate iron, attached to the carriage, clasps the two timbers. An axle provided with a cam in the middle, operated by a lever, is placed across the front end of the slide passing through the space between the friction timbers. Obviously these timbers will be pushed apart with considerable force if the transverse axle be turned so as to place the cam in a vertical position. The friction between the hoop and the

timbers produced by the pressure of the cam, it is scarcely necessary to observe, will be greatly enhanced during the recoil of the gun, in consequence of the increasing vertical depth of the timbers towards the rear end of the slide. The transverse axle being turned so as to place the cam in a horizontal position, permitting the friction timbers to approach each other, will, of course, at once relieve the friction. The monitor gun-carriages, constructed, like the *Princeton's*, on the plan of checking the recoil by friction, differed as regards the mode of clasping the friction timbers, a *screw* being employed to produce the requisite compression in place of the transverse axle and its cam. But in constructing gun-carriages for the celebrated thirty Spanish gunboats, and in all recent carriages, I have returned to the plan of employing a cam for setting up and relieving the friction, whereby, as in the case of the *Princeton* carriage, the operation becomes almost instantaneous.

The 12-in. wrought-iron gun of the *Princeton*, as stated, was manufactured at the Mersey Iron Works, of the very best materials, it has been asserted; but, on being tested in this country, it proved too weak. I therefore resorted to the expedient of hooping the breech of the piece up to the trunnion band; the hoops being made of the best quality of American wrought-iron put on in two tiers, shrunk one over the other in such a manner as to break joint. This expedient proved entirely successful, the gun having stood all tests to which it has been subjected. It was a solid cast-iron shot from this 12-in. gun which in 1842 pierced a wrought-iron target $4\frac{1}{2}$ in. thick, up to that period considered proof against naval ordnance.

The United States Government having been the first to introduce heavy wrought-iron ordnance for naval purposes, why does it not continue to build guns of that material? European artillerists repeatedly put this question. Probably the answer will be found in the fact that, although having in the meantime successfully constructed rifled wrought-iron ordnance of considerable size, the first essay at building heavy guns for naval purposes proved most disastrous. Immediately after the trial of the gun referred to, manufactured in England, a 12-in. smooth-bore, of much heavier metal, was forged at Hamersley Forge, bored and turned in New York, considered at the time to be a remarkable specimen of good workmanship. It was at once mounted on board the *Princeton*, by the side of its slender companion, upon a similar carriage. Much confidence was placed in the strength of this magnificent gun on account of the supposed superior quality of American iron. It stood the proof-charge and some preliminary tests, but, on being fired on a festive occasion while the ship was at Washington, the admired piece burst, with the sad result recorded in the naval annals of the time.

APPLICATION OF THE SUBMERGED PROPELLER FOR COMMERCIAL PURPOSES.

During the construction of the *Princeton* numerous propeller-vessels were built for carrying freight on the rivers and inland waters of the country, the machinery at first being built in New York, Philadelphia, and Oswego. The line of propeller-steamers between Philadelphia and Baltimore, which seriously interfered with the freight traffic of the Philadelphia and Baltimore Railroad, merits special mention.

The annexed table of propeller-vessels built up to December, 1843, prepared by Lieutenant Johnson, of the Swedish Navy, in pursuance of orders from his Government, shows the extraordinary rapidity of the adoption of the propeller for commercial purposes.

The London *Engineer*, in laying the table referred to before its readers, May 11, 1866, observes:

"The fate of mechanical inventions is much like that of the seed in the parable. The invention must fall on a proper soil, and be nurtured by favorable circumstances of time and place,

List of Steam Vessels in North America provided with Ericsson's Screw-Propeller up to December, 1843.

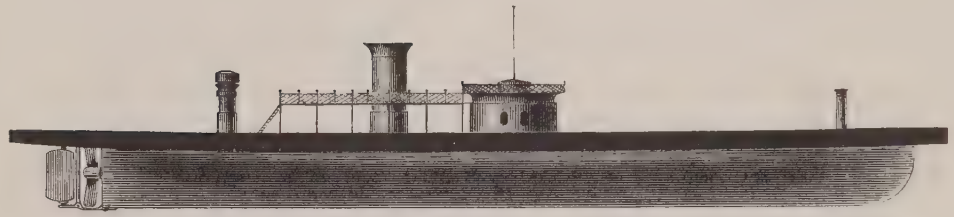
Names of the Vessels.	Destination.	Number of Cylinders.	Horse-power.	Burthen in Tons.	Length.	Beam.		Depth of Hold.		Propeller Diameter.		When Built.
						Ft.	*In.*	*Ft.*	*In.*	*Ft.*	*In.*	
Robert F. Stockton.	Delaware and Schuylkill.	2	60	42	70	10	0	7	0	6	4	1839
Vandalia.....	Oswego to Chicago.....	2	40	140	98	21	6	6	6	5	9	1841
Clarian	New York to Havana....	1	60	250	104	24	6	13	0	6	4	"
Baron Toranto.....	Rideau Canal and St. Lawrence	1	18	70	72	16	6	4	6	5	9	"
Royal Barge.....	Rideau Canal and St. Lawrence	2	36	70	72	16	6	4	6	5	9	"
Propeller.....	Rideau Canal and St. Lawrence	1	18	70	72	16	6	4	6	5	9	"
Ericsson	Rideau Canal and St. Lawrence	1	18	70	72	16	6	4	6	5	9	"
Ironside	Philadelphia to Albany..	1	40	200	100	22	6	6	0	6	0	1842
Anthracite	" " ..	1	40	200	100	22	6	6	0	6	0	"
Black Diamond....	Philadelphia to Hartford.	1	40	200	100	22	6	6	0	6	0	"
Vulcan	" "	1	40	200	100	22	6	6	0	6	0	"
Pioneer	Erie Canal.....	1	18	55	82	14	4	3	6	5	6	"
Oswego	Oswego to Chicago.....	2	40	140	98	21	6	6	6	5	9	"
Chicago	" "	2	40	140	98	21	6	6	6	5	9	"
Cumberland.....	Philadelphia to Baltimore	2	40	80	78	18	6	6	6	6	6	"
Ericsson	" "	2	40	80	78	18	6	6	6	6	6	"
Pilot.....	New York to Canada....	1	18	55	82	13	6	3	6	5	6	1843
Phœnix.....	" "	1	18	55	82	13	6	3	6	5	6	"
Governor McDowell	James River Canal to Virginia	1	18	20	90	13	6	1	2	5	0	"
Jefferson (Revenue Cutter)	Lake Erie.....	1	150	342	140	24	0	7	6	9	6	"
Legare	Delaware River	1	150	342	140	24	0	7	6	9	6	"
Hercules.....	Lake Erie.....	2	50	250	..	..		8	0	6	0	"
Perrysborough.....	" "	2	50	250	..	..		8	0	6	0	"
Cleveland.....	" "	1	60	280	..	..		8	0	6	10	"
Baltimore.....	Philadelphia to Baltimore	1	50	127	78	19	6	6	6	7	2	"
Princeton.....	Philadelphia Station.....	2	400	672	164	30	0	17	6	14	0	"
Lion.....	New York to Hartford...	1	50	172	115	23	6	6	0	6	10	"
Eagle	" " ...	1	50	172	115	23	6	6	0	6	10	"
Mohawk	Albany to Hartford.....	1	50	172	125	22	0	6	0	7	0	"
C. Bristol	Chicago and the Great Lakes	1	60	300	..	26	0	8	0	7	4	"
New London.....	Mobile.....	1	50	172	125	22	0	6	0	7	0	"
Uncas	"	1	50	172	125	22	0	6	0	7	0	"
New London.....	Owners, Williams & Barns	2	50	172	125	22	0	6	6	7	0	"
Enterprise.....	Lake Ontario and St. Lawrence	1	20	70	..	..		..		5	9	"
New York.....	Oswego to Chicago.....	2	50	140	98	21	6	6	6	5	9	"
Washington.....	Hudson River.....	1	60	170	103	26	0	7	6	7	4	"
Rufus Page, Owner.	East Coast of America...	1	50	172	115	23	6	6	0	6	10	"
Rufus Page, Owner.	" " ...	1	50	172	115	23	6	6	0	6	10	"
Buck, Owner..	" " ...	2	55	172	125	22	0	6	0	7	0	"
Captain Sanford, Owner	" " ...	2	55	172	125	22	0	6	0	7	0	"
Williams & Barns..	" " ...	2	55	172	125	22	0	6	0	7	0	"
Captain Coit	" " ...	2	55	172	125	22	0	6	0	7	0	"

in order to bloom into success. The application of the steam-engine to navigation was of greater necessity to the large extent of the rivers and lakes of the States than with ourselves; and Fulton did right to take his marine engine back to his own country. For similar reasons the screw-propeller worked its way into use there much quicker than with ourselves. This fact is very evident from the table furnished to Mr. Woodcroft by Captain Ericsson, prepared by Lieutenant Johnson, of the Swedish Navy, in 1843. Early in the following year (1844) a very large addition was made to the steam fleet provided with Ericsson's propeller both on the inland waters of America and on the ocean. Of the latter may be mentioned the bark *Edith* and the steamships *McKim*, *Marmora*, and *Massachusetts*. The last vessel was subsequently purchased by the United States Government. It became the flag-ship of General Scott at the landing of Vera Cruz, which resulted in the conquest of Mexico. It is worthy of notice that Ericsson applied his propeller to upwards of sixty vessels in America before any other form of propeller was adopted or a single attempt made at evading his patent. Nor is it less worthy of remark that the adaptation of his propeller proved a great commercial success from the start, many of the original vessels being now, after fifteen years of service, in good working condition."

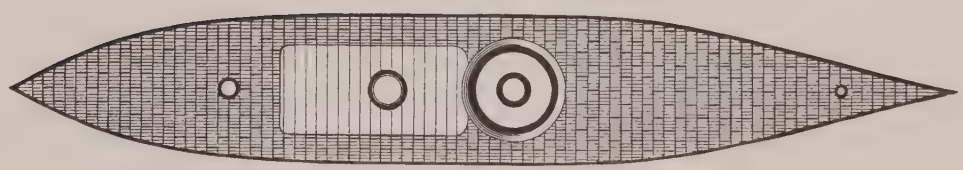
THE MONITOR DICTATOR.

DESIGNED BY JOHN ERICSSON. BUILT AT NEW YORK 1862.

SIDE ELEVATION.



DECK PLAN.



Length on deck, 312 feet. Beam, 50 feet. Depth, 21 feet 6 inches.

Steam Cylinders, 100 inches diameter, 4 feet stroke. Propeller, 21 feet 6 inches diameter.

THE MONITOR SYSTEM AND THE CENTENNIAL EXHIBITION.

The imperfect character of the monitor turret exhibited in Fairmount Park has been noticed with surprise by professional visitors. In view of the important results attained by the adoption of this structure during the war, it cannot be denied that a painted wooden representative is unworthy of the occasion. Nor need it be urged that some turret bearing the marks of actual conflict ought to have been transferred to the Exhibition. Experts are aware that, owing to the laminated character of these turrets, they may readily be taken down, and the plates transported and put up at any required distance from the vessel. Besides, it may be shown that this process would have been less expensive than erecting a complete representative turret and mechanism. Regarding the armament applied within the wooden turret, naval artillerists from abroad, who expected to have had an opportunity of examining the detail of the friction-gear peculiar to the monitor armament, are greatly disappointed to find that, instead of the car-

riages on which the guns were mounted during the war, an experimental steam-carriage devised by Mr. J. B. Eads, after the war, has been placed in the representative turret. In consequence of this unintentional misleading procedure on the part of the authorities, of excluding the carriages which had been used, the majority of visitors naturally imagine that the monitor guns, during the war, were operated by Eads's experimental device.* It should be mentioned that the plan of checking the recoil of our guns by friction has not been superseded in the navy, and that friction gun-carriages are at present being constructed for the Navy Department under my patents.

THE PILOT-HOUSE.

The pilot-house—wheel-house—of the monitors, and the steering-gear which it contains (see illustration), forming the most important features of the system, their exclusion from the turret at the Centennial Exhibition is a remarkable circumstance. It cannot be supposed that the officer charged with the duty of putting up the representative turret would incur the responsibility of excluding without authority that part of the system which most interests the professional visitor. The country is aware that Admiral Porter's report to the Secretary of the Navy, published while the preparations for the Centennial Exhibition were in progress, contained a recommendation to abolish the pilot-house of the monitor turrets. Possibly this recommendation, condemnatory of my invention, has led to the exclusion of the steering machinery and

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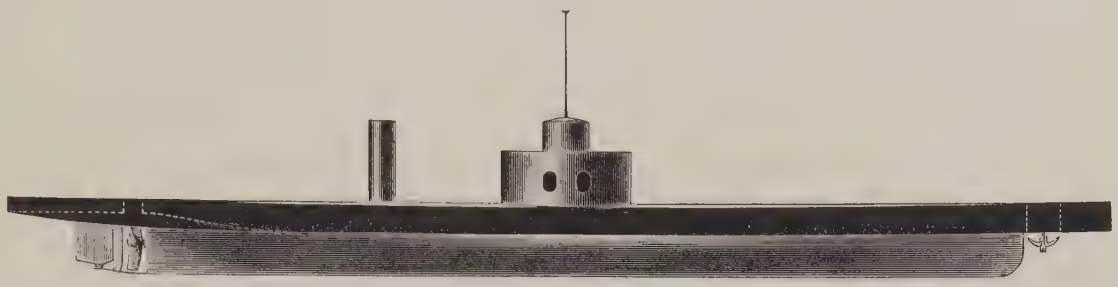
* My circular friction-carriage, exhibited in the wooden turret, was applied in the *Dunderberg*, but not in the monitors during the war.

MONITOR OF THE PASSAIC CLASS.

DESIGNED BY JOHN ERICSSON.

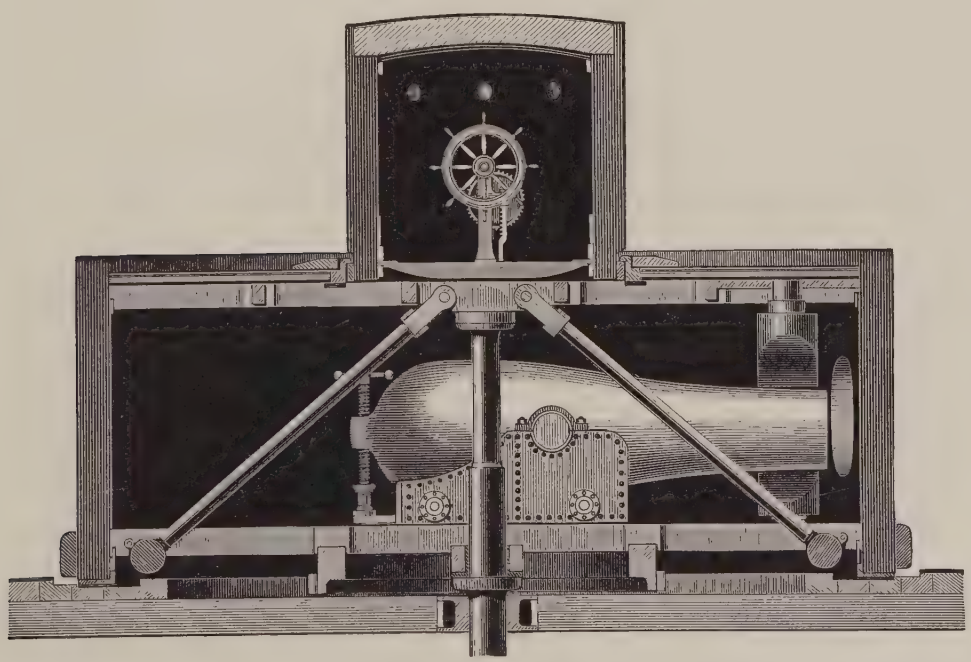
TEN MONITORS OF THIS CLASS BUILT AT NEW YORK AND OTHER PLACES.



TRANSVERSE SECTION OF TURRET AND PILOT-HOUSE.

DESIGNED BY JOHN ERICSSON.

BUILT AT NEW YORK, WILMINGTON, AND OTHER PLACES.



the massive pilot-house from the representative turret in Fairmount Park. I do not propose to investigate the cause which has led to the exhibition of my invention in a mutilated state, but I feel called upon to show that the removal of the pilot-house from the turrets recommended by Admiral Porter is incompatible with the monitor system.

Well-informed naval officers are aware that Worden failed to sink the *Merrimac* at Hampton Roads because he could not personally control the firing and at the same time direct the steering of his vessel from a point enabling him to observe properly the movement of his antagonist. This fact was well understood by the authorities at Washington, the Assistant Secretary of the Navy having himself witnessed the battle and the ineffectual firing. I was accordingly requested by the Navy Department, shortly after the conflict, to devise some means of *steering from the turret.* The despatch conveying this request contained several important suggestions, and closed with the following sentence: "The placing the wheel-house on the turret would double the formidable character of the vessel." Considering what happened at Hampton Roads, more might have been said; for had the *Monitor* been provided with a wheel-house on the top of the turret, Worden, instead of discontinuing the action almost blinded, would have forced the *Merrimac* to surrender as readily as Rodgers compelled the commander of the boasted impregnable *Atlanta* to haul down the Confederate flag by being enabled personally to direct the steering and the firing while watching from the elevated turret wheel-house of the monitor *Weehawken* the movements of his opponent. Again, it was from the turret wheel-house of the monitor *Montauk* that the

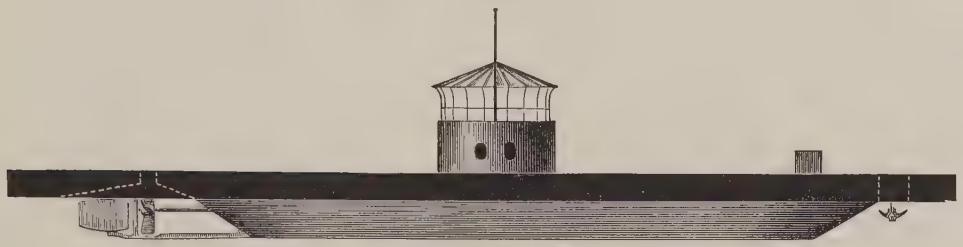
hero of Hampton Roads detected the *Nashville*, and by a few fifteen-inch shells, fired under his own supervision, burnt the Confederate vessel and cargo. It was reserved for the Admiral of the Navy to discover that the arrangement which enables the commander of a monitor to direct the firing and the steering from an elevated position above the turret, affording an all-round view, is a terrible mistake, although it has proved so efficacious in actual conflict. It was reserved for him also to find out "that the placing of the pilot-house on the top of the monitor turret shows a lack of ingenuity"—a discovery apparently resulting from reflections connected with the fact mentioned in his report, "that this is the most exposed point in the vessel, and is liable to be swept way by the first heavy shot that strikes." The Admiral appears to have forgotten that the fleet of monitors at Charleston, commanded by Dahlgren, engaged the Confederate batteries some twenty times, at easy range, and yet the pilot-houses were not "swept away."

The accompanying section of the turret and wheel-house (pilot-house) of a monitor of the *Passaic* class represents the structure precisely as built, excepting that the turret wall, in order to protect the base of the wheel-house in accordance with my original plan, is carried two feet above the turret roof (indicated by dotted lines in the engraving). As the wheel-house and steering gear must remain stationary while the turret revolves, it will be perceived that the plan presents a mechanical problem of no ordinary character. This is understood by persons possessing correct mechanical knowledge, who have studied the arrangement, and know that it successfully passed the severe ordeal to which it was subjected during the war.

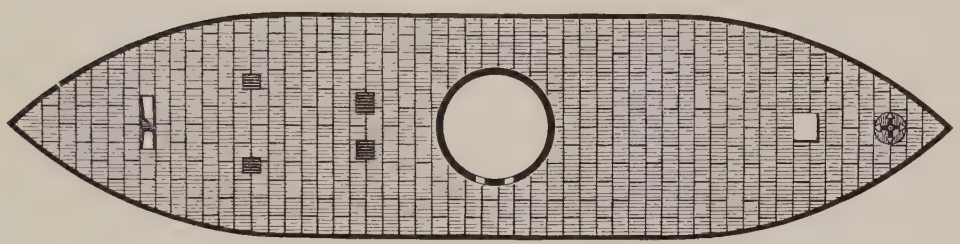
THE MONITOR.

DESIGNED BY JOHN ERICSSON. BUILT AT NEW YORK 1861.

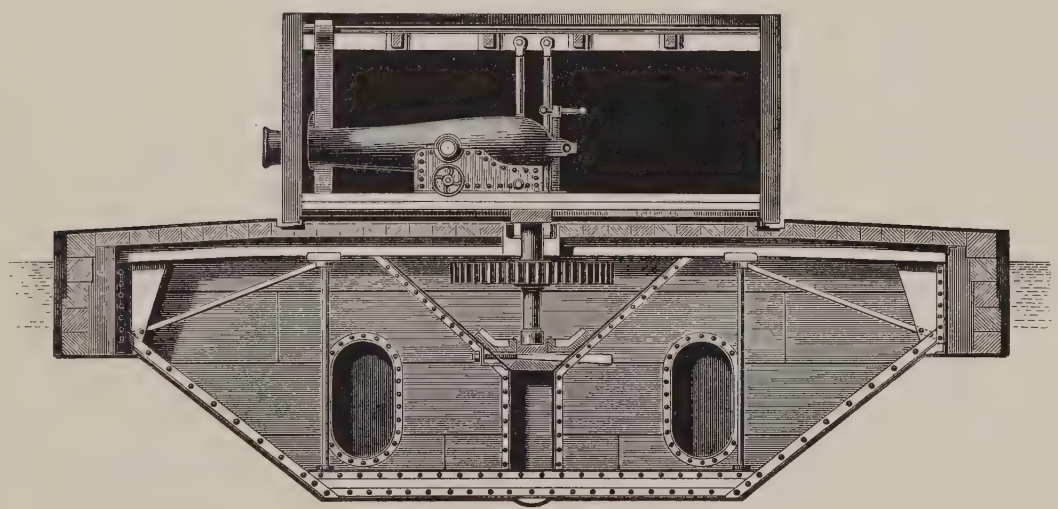
SIDE ELEVATION.



DECK PLAN.



TRANSVERSE SECTION OF HULL AND TURRET.



With reference to the original plan of extending the turret wall above the roof, it will be proper to mention that the managers of the plate mills employed to manufacture the turret plating during the war refused to furnish plates of more than nine feet in length. Not only did they positively decline to roll plates of an *additional* length of *six* inches, but they limited the thickness to fifteen-sixteenths of an inch, owing to their inability to manufacture plating above a given weight. Those who criticise the strength of the armor of the monitors will do well to bear this in mind. A careful inspection of the accompanying illustration, representing a section of the turret of the *Passaic* class of monitors, at once disposes of the erroneous assertion that the pilot-house, the internal diameter of which is only six feet, may be "swept away." No target practice has yet shown that a cylinder of such small diameter, composed of solid iron eighteen inches thick (of course it might be made thicker), can be penetrated. At the same time, the inertia of such a cylinder, owing to its weight, is so great that a base-ring of very moderate section attached to the turret roof will effectually prevent dislodgment under the impact of shot.

In view of the foregoing, it would be waste of time to discuss the merits of the Admiral's recommendation to the Secretary of the Navy, "to place the steering apparatus below, with a small portion of the deck above it raised and heavily plated, with apertures to look through." But his reference to lack of strength calls for some notice. In reply, I will simply observe that by substituting solid for laminated armor, the original *Monitor*, "if in existence to-day," would be the most formidable iron-clad of her tonnage possessed by any naval

power. Of course it must be attributed to inadvertency that Admiral Porter has not, in his report, reminded the Secretary of the Navy that the laminated armor of the turrets of the entire monitor fleet ought to be at once substituted by solid plating.

Naval constructors and engineers will find by examining our illustrations that, excepting the omission to place the pilot-house on the top of the turret, the original *Monitor* was a perfect fighting machine; and that not a single essential improvement has been added in building the subsequent monitor iron-clads. It will also be found that the propeller was better protected in the original *Monitor*, and that the anchor was handled with greater facility and more perfect protection to the crew, than in the recent turret-vessels. Moreover, it is susceptible of positive demonstration that a vessel built precisely like the first *Monitor*, provided with a turret wheel-house and armor of adequate thickness, would present the most perfect vessel for harbor defence hitherto produced—whether for carrying heavy ordnance, or for handling movable torpedoes employed against an attacking fleet.

It will be observed by those who have studied the matter that Admiral Porter's statement, at the commencement of his report, is materially modified by a subsequent paragraph, strongly recommending the *overhang* of the *Monitor*, "which," the report states, "prevented the hull being penetrated if the vessel was struck by a ram." The Admiral further observes: "The value of this contrivance was shown in the contest at Hampton Roads, where the *Merrimac* rammed the *Monitor*, merely turning the latter half round, and doing no damage whatever." It will be seen, by the illustration representing a

transverse section of the original *Monitor*, that a collision like that between the *Iron Duke* and the *Vanguard*, which sent the latter to the bottom, would not be productive of greater damage than that caused by the *Merrimac's* ramming, since, owing to the overhang and inclined sides, the *Iron Duke's* spur could not reach the *Monitor's* hull.

THE CALORIC ENGINE.

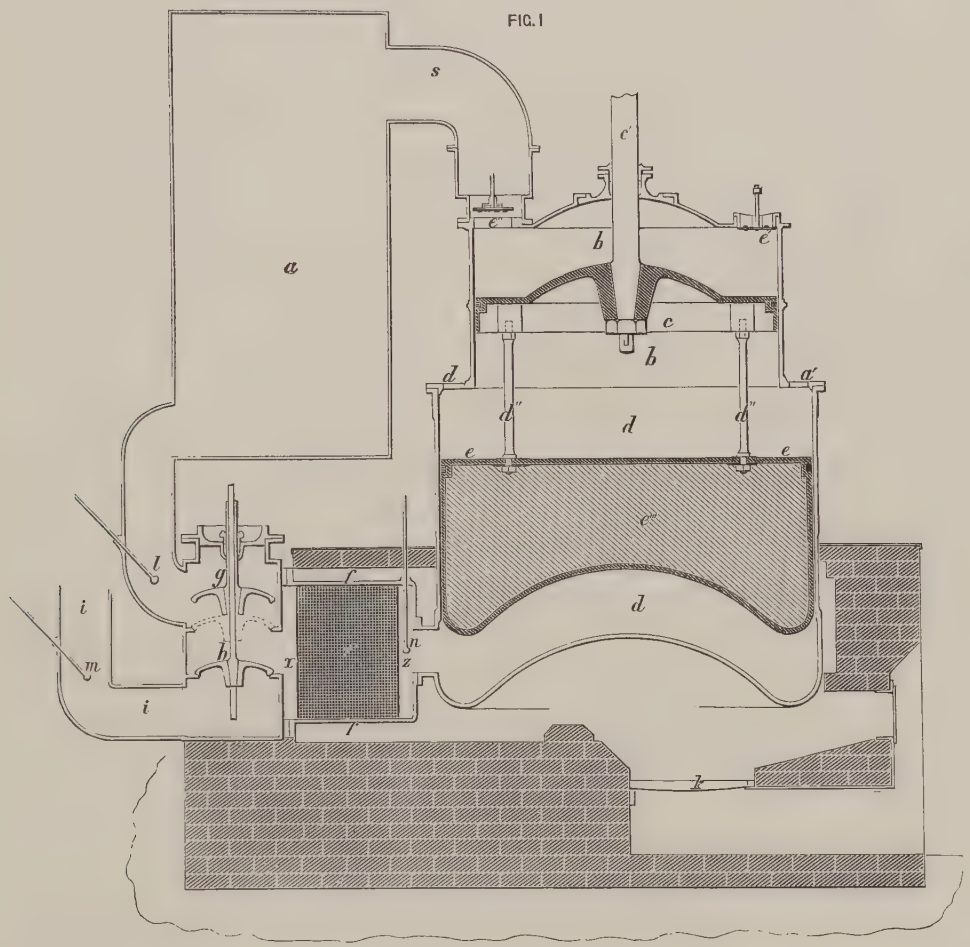
THE APPLICATION OF HEATED AIR AS A MOTOR.

Engineers are aware that I built a caloric engine in London, 1833, operated by heated atmospheric air; Faraday, Ure, and Lardner taking great interest in the same in consequence of its being based on the principle of returning, at each stroke of the working piston, the heat not converted into mechanical work during the previous stroke. After my arrival in this country, 1839, I prosecuted the plan and built several caloric engines in succession, all of which promised ultimate success. At each step the dimensions were enlarged, until, 1851, I produced an experimental engine having two working cylinders of seventy-two inches diameter, two feet stroke, and two compressing cylinders of fifty-eight inches diameter (see annexed sectional illustration). The leading feature of this large caloric engine was that of circulating the heated air, as it passed off from the working cylinder, through a series of wire discs containing an aggregate of 13,520,000 meshes for each working cylinder. The cold air in entering the engine was admitted through the

EXPERIMENTAL CALORIC ENGINE OF 1851.

TRANSVERSE SECTION OF ONE PAIR OF CYLINDERS, FIRE-PLACE, REGENERATOR, AND VALVES.

FIG. 1



meshes of the heated discs, taking up nearly the whole of the heat previously imparted by the exhaust air in its passage through the meshes, on its way to the atmosphere. The regularity of action and perfect working of every part of this experimental engine, and, above all, its apparent great economy of fuel, induced some enterprising merchants of New York, in the latter part of 1851, to accept my proposition to construct a ship for navigating the ocean propelled by paddle-wheels actuated by the caloric engine. This work was commenced forthwith, and pushed with such vigor that within nine months from commencing the construction of the machinery, and within seven months from laying the keel, the paddle-wheels of the caloric ship *Ericsson* turned round at the dock! In view of the fact that the engines consisted of *four* working cylinders of 168 inches diameter, 6 feet stroke, and *four* air-compressing cylinders of 137 inches diameter, 6 feet stroke, it may be claimed that, in point of magnitude and rapidity of construction, the motive machinery of the caloric ship stands unrivalled in the annals of marine engineering. It may be added that the principal engineers of New York all expressed the opinion that a better specimen of workmanship than that presented by the huge machinery of the caloric ship had not been produced by our artisans up to that time.

The following data, published in *Appleton's Mechanics' Magazine*, will interest the professional reader:

DIMENSIONS OF THE ERICSSON.

Length on deck,	260 feet.
Length of keel,	250 "
Breadth of beam,	40 "
Depth of hold,	27 "
Draught of water on trial-trip,	17 "

Diameter of wheels,	32 feet.
Length of bucket,	$10\frac{1}{2}$ "
Breadth of bucket,	20 ins.
Dip of wheel (supposed about),	2 feet.

ENGINES.

Number of working cylinders or single-acting air-engines,	4
Diameter,	168 inches.
Area of piston,	22167.0773856 sq. in.
Stroke,	6 feet.
Portion of stroke from commencement at which air is "cut off," about,	$\frac{63}{100}$
Cubical contents of each working cylinder,	1596024 cub. in.
Cubical contents of $\frac{63}{100}$ of working cylinder,	995495 "
Number of supply cylinders or single-acting pumps,	4
Diameter,	137 inches.
Area of piston or plunger,	14741 sq. in.
Stroke, necessarily,	6 feet.
Cubical contents of each pump,	1061352 cub. in.
Number of regenerators,	4
Number of discs of iron-wire netting in each regenerator,	50
Height of each disc,	6 feet.
Width,	4 "
Size of wire,	$\frac{1}{16}$ inch.
Ratio of area of openings in the netting to total area of disc,	$\frac{1}{2}$ to 1
Total area of opening of "air way" through each disc, $\frac{6 \times 4}{2} =$	12 sq. ft.
Greatest or total heat of air in working cylinder above atmosphere,	384° F.
Heat of issuing air above atmosphere,	30° F.
Pressure necessary to move the engine,	$\frac{1}{2}$ lb.
Coal consumed in the four furnaces per day,	6 tons.
Maximum coal possible to consume in the four furnaces per day,	7 tons.
Number of smoke-pipes,	2
Number of air-pipes,	2
Height of each smoke and air pipe above deck,	12 feet.
Diameter " " "	30 inches.
Amount of air passing through the four cylinders per hour,	50 to 75 tons.

Depth of working piston, or thickness,	6 feet.
Thickness of cylinder-bottom,	$1\frac{1}{2}$ inches.
Distance of grate from bottom of cylinder,	5 feet.
Ordinary pressure of the engine per square inch,	12 lbs.
Actual pressure on the second trial-trip, January 11,	8 "
Number of revolutions under pressure of 8 lbs. on trial-trip,	9
" " expected with 12 lbs. pressure,	12
Miles per hour obtained on trial-trip, January 11, allowing for tide, etc.,	7
Miles per hour expected with 12 lbs. pressure,	10 to 12
Number of meshes in each disc,	500000
Temperature in working cylinder, $60° + 384° =$	440°
Common temperature of the atmosphere (usual assumption),	60°
Specific heat of air—water being 1000,	.2669
Common pressure of air per square inch = 14.73 lbs., say	15 lbs.
Weight per cubic foot, common pressure and temperature, = .0752914 lbs., say	$\frac{1}{13}$ lb.
Density of air, temperature remaining constant, is directly as the pressure.	
Weight per cubic foot, at 12 lbs. pressure, common temperature,	$\frac{27}{195}$
Expansion of air at 32° for each degree added, according to Rudberg,	$\frac{1}{493}$
Dalton and Gay-Lussac, .00208; Regnault, $\frac{1}{491}$; common estimate,	$\frac{1}{480}$
Expansion of air at 60°, for the 384° added,	$\frac{384}{508}$
Density of air at $(60° + 384° =)$ 444°, compared with air at 60°, as	$\frac{508}{508 + 384}$ to 1
Weight of a cubic foot at 12 lbs. pressure, temperature $444° = \frac{508}{892} \times \frac{27}{195} =$	$\frac{13716}{173840}$ lb.
Weight of 995495 cubic inches at 12 lbs. pressure, temperature $444° = \frac{995495}{1728} \times \frac{13716}{173840} =$	46 lbs.
Therefore, air passed through each cylinder each stroke,	46 "
Weight of 1061352 cubic inches, at common temperature and pressure $= \frac{1061352}{1728} \times \frac{1}{13} =$	47.153 lbs.
Therefore, air passed each pump each stroke,	47 "
Allowance made for clearance, leakage, etc., per stroke, $47 - 46 =$	1 lb.
Units of heat required to raise 47 lbs. air $384° = 47 \times 384 \times .2669 =$	4817 units.

Units of heat retained by the 47 lbs. on escaping = 47 × 30 × .2669 = ...	376 units.
Units of heat transferred by the regenerator each stroke, .	4441 "
Absolute theoretical consumption of heat, per stroke, per cyl.,	376 "
Mean pressure, per square inch, on working piston, allowing for continued addition of heat while expanding, initial pressure being 12 lbs., about	10.8 lbs.
Mean force acting upon working piston, 10.8 × 22167 = .	239403.6 "
Mean resistance per square inch to supply piston, commencing with 0, and increasing to 12 lbs., at which pressure it continues to end of stroke.	
[The mean resistance in compressing an elastic fluid may be found by reversing the ordinary calculation on expansive working.	
The hyp. log. of $\frac{15}{27}$ is .588] 1.588 × 12 × $\frac{15}{27}$ = ...	10.5555 lbs.
Mean resistance against supply-piston 10.5555 × 14741 = .	155598 "
Balance tending to move the engine, 239403 — 155598 = .	83805 "
Units of power theoretically obtainable per stroke = 83805 × 6 = ...	502830 units.
Units of power theoretically obtainable from each unit of heat,	1337 "

The ship after completion made a successful trip from New York to Washington and back during the winter season; but the average speed at sea proving insufficient for commercial purposes, the owners, with regret, acceded to my proposition to remove the costly machinery, although it had proved perfect as a mechanical combination. The resources of modern engineering having been exhausted in producing the motors of the caloric ship, the important question has for ever been set at rest: Can heated air as a mechanical motor compete on a large scale with steam? The commercial world is indebted to American enterprise—to New York enterprise—for having settled a question of such vital importance. They have thus encouraged the marine engineer to renew his efforts to perfect the steam-engine, without fear of rivalry from a motor depending on the dilatation of atmospheric air by heat.

But although the caloric engine has proved inapplicable to navigation, it has been found to be of very great utility as a domestic motor.

The following interesting article in the New York *Tribune* of May 5, 1860, shows how rapidly the caloric engine was adopted after its adaptation to domestic purposes:

"*The New Motor.*

"It is some eighty-six years since Mr. Boulton, at the great steam-engine works of Soho, made use of the memorable expression to Boswell: 'I sell here, sir, what all the world desires to have—POWER.' The mechanical world has been occupied from that time to the present with this problem of power, and mechanical ingenuity has tasked and exhausted itself with efforts to construct a machine that should prove an efficient auxiliary or rival of the steam-engine. And it is most extraordinary that, notwithstanding the amount of inventive genius and science that has been expended in this special field of labor, literally nothing had been accomplished of any practical importance till Ericsson produced the caloric engine, in the particular form and with the peculiar devices which distinguish it from all the engines actuated by heat, that have been built at such an enormous expense of time and money.

"Motive engines of a moderate or even of a small power play a very important part in the economy of human life. The frightful horrors of the slave-trade; the scarcely less frightful horrors of the traffic in Coolies; nay, the haggard features and jaded limbs that, in our great cities more especially, speak so distinctly of over-wrought human labor, and cry out so emphatically for relief—all these demonstrate that a compact, manage-

able, safe, and economical motor, adequate to the work of a *single* slave or Cooly, or overtasked white man or white woman, would do more to mitigate the suffering and diminish the drudgery of mankind than any other conceivable invention. After all the enormous accumulations of steam-power, water-power, wind-power, and horse-power, and their vast achievements, by how much the larger amount of power exercised in the world is the aggregate result of individual force applied to the thousands of little things that occupy the human family in the daily routine of living! Combine these forces, and what a stupendous whole they exhibit! Make an available motor that shall be of one-man power, and what a result is obtained! Make a motor perfectly safe, easily kept in order, requiring no water, and consuming but little fuel, of the power of a single horse, to what an extent the aggregate result is augmented, and what an importance in human affairs such a machine assumes!

"If Ericsson's caloric engine, then, claimed to be nothing but such a motor, it would be a subject well deserving the most earnest and serious investigation; but the proof is accumulated, of a nature that compels belief and defies contradiction, which demonstrates the existence in this engine of a power entirely sufficient for all but a very few of the thousand uses for which power is required.

"It is not material to our purpose to indulge in any retrospective review of Ericsson's labors. It is well known that this grand invention has occupied thirty years of his life, during which he has built many engines of the largest size and uncounted experimental engines of smaller power.

"We have seen an official statement in relation to an engine put up about a year since to supply the locomotives at

the South Groton Station, on the same railroad. From April, 1859, to April, 1860, this engine pumped 1,600,000 gallons of water, at an expense to the company for fuel and oil of $25, and for an 'engineer' $25, and has not cost one cent for alteration or repairs.

"A result more important, in view of the number of engines employed, is exhibited on the New York Central Railroad, on the line of which there are now some twenty of these engines in daily use. Mr. Chauncey Vibbard, the Superintendent of that road, reports, over his official signature, after several months' experience with a number of these engines, that they perform an 'incredible' amount of labor 'for the small quantity of fuel consumed.' One of them, he says, for $\frac{96}{100}$ of a cent per hour, does the work formerly done by four men at an expense of $25 each per month. Another, of the same size, at the Savannah Station, at an expense of eleven cents a day, does the work of five men who receive $125 a month. Other engines have been erected on several other railroads for pumping purposes with the same favorable result.

"The second application of the caloric engine was to the driving of printing-presses. The first trial of the engine for this purpose was made in the office of the *Hartford Times* —the first that was entirely successful was made in the office of T. W. Strong, No. 98 Nassau Street, in this city. The next engine built was set up in the office of Messrs. French & Wheat, No. 18 Ann Street, and the third in the office of Mr. C. C. Shelley, a job-printer in Barclay Street. The result has been the adoption of the engine in numerous job-offices in every part of the country. There are now no less than forty daily papers in the United States printed by Ericsson's en-

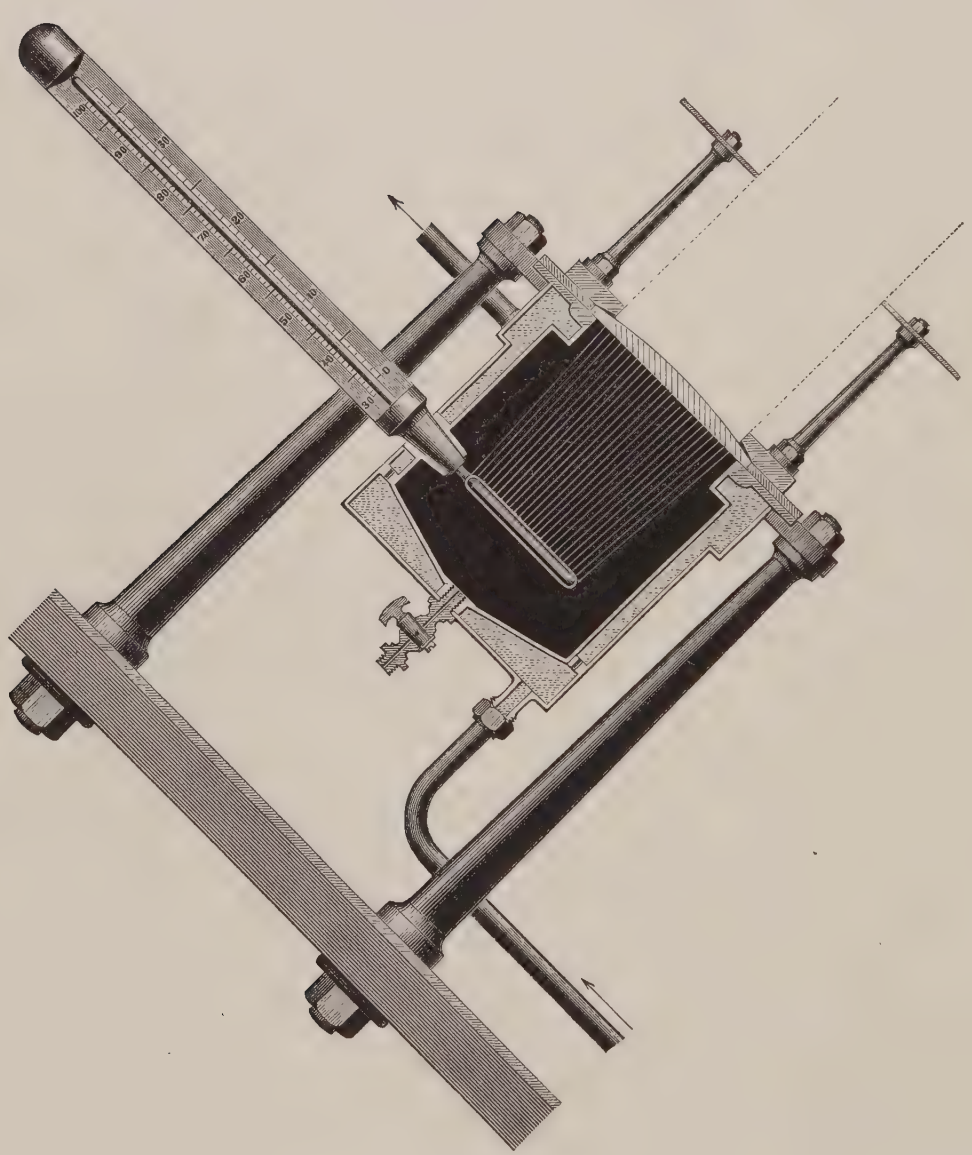
gines, most of them of 24-inch, but three or four of 12 and 18 inch cylinders. One of the most recent testimonials to its value is from the proprietor of the *Savannah Evening Express*, who states that he regards it as the most perfect and economical motive power ever applied."

Several thousand caloric engines were subsequently constructed in this country and in Europe; but steam-engineers, finding by the extraordinary demand for caloric engines that very moderate power was a great desideratum, have perfected the steam-motor until it almost rivals the caloric engine in safety and adaptability; consequently, the demand for caloric engines has been greatly diminished of late. Yet this motor can never be superseded by the steam-engine, since it requires no water, besides being absolutely safe from explosion. There are innumerable localities in which an adequate quantity of water cannot be obtained or prevented from freezing, but where the necessities of civilized life call for mechanical motors; hence the caloric engine may be regarded as an institution inseparable from civilization.

ACTINOMETER.

DESIGNED BY JOHN ERICSSON.

MANUFACTURED AT NEW YORK, 1870.



SOLAR ENERGY.

I have during the last seven years constructed several model engines operated by concentrated solar heat; and a great variety of instruments for ascertaining the maximum intensity of solar radiation and the mechanical energy actually developed by the sun's radiant heat.

THE ACTINOMETER.

The accompanying illustration represents a vertical section of an instrument constructed for ascertaining, by a new and exact method, the intensity of solar radiation at the surface of the earth, specially arranged for revolving observatories. Sir John Herschel's definition of the word *actinometer*—"an instrument for measuring the intensity of heat in the sun's rays"—warrants the adoption of that term.

The causes which modify the intensity of solar radiation are chiefly: the position of the earth in its orbit, the sun's zenith distance—on which depends the depth of the atmosphere to be penetrated by the rays—and vapors in the atmosphere. The temperature of surrounding objects which radiate towards substances exposed to the sun's rays, and the heat abstracted

Time of observation.	TEMPERATURE, A.M.				Differential temperature or solar intensity.	
	In the sun.		In the shade.			
	° *Fah.*	° *Cent.*	° *Fah.*	° *Cent.*	° *Fah.*	° *Cent.*
9.00	93	33.88	68	20.00	25	13.88
9.30	103	39.44	69	20.55	34	18.89
10.00	111	43.88	70	21.11	41	22.77
10.30	119	48.33	71	21.66	48	26.67
11.00	124	51.11	71	21.66	53	29.45
11.30	125	51.66	72	22.21	53	29.45
12.00	129	53.88	73	22.77	56	31.11

Time of observation.	TEMPERATURE, P.M.				Differential temperature or solar intensity.	
	In the sun.		In the shade.			
	° *Fah.*	° *Cent.*	° *Fah.*	° *Cent.*	° *Fah.*	° *Cent.*
12.30	132	55.55	74	23.33	58	32.22
1.00	141	60.55	74	23.33	67	37.22
1.30	140	60.00	75	23.88	65	36.12
2.00	143	61.66	75	23.88	68	37.78
2.30	138	58.88	76	24.44	62	34.44
3.00	138	58.88	76	24.44	62	34.44
3.30	132	55.55	77	25.00	55	30.55
4.00	124	51.11	76	24.44	48	26.67
4.30	123	50.55	77	25.00	46	25.55
5.00	112	44.44	76	24.44	36	20.00
5.30	106	41.11	75	23.88	31	17.23
6.00	100	37.77	73	22.77	27	15.00

from such substances by currents of air, present serious disturbing elements, rendering an accurate determination of the radiant intensity by ordinary thermometers practically impossible. It is hardly necessary to point out that solar intensity cannot be satisfactorily ascertained by the old method of deducting the temperature of a thermometer in the shade from that of another thermometer exposed to the sun. The investigations of Daniell relating to the sun's radiant heat, frequently referred to in works on meteorology, conducted in the latitude of London, where the depth of the atmosphere at noon, during the summer solstice, is 0.57 greater than on the ecliptic, merit serious consideration. The subjoined table contains the result of his observations on solar radiation throughout a day in the month of June.

A glance at this table shows that, according to the adopted method of determining the intensity of solar radiation by deducting the temperature indicated by a thermometer in the shade from the temperature attained in the sun, the radiant heat is considerably less before than after noon. The differential temperature, or solar intensity, at 9 A.M., according to this table, is 25°, while at 3 P.M., with an equal zenith distance and equal depth of atmosphere to penetrate, the solar intensity is stated to be 62°, thus exhibiting the enormous difference of 27°. An explanation of the causes of the extraordinary errors of Daniell's table is scarcely needed, but attention should be called to the gross imperfection of such a mode of determining solar radiation as that of noting the different indications of shaded and exposed thermometers.

The annexed tables exhibit the result of investigations conducted by means of the actinometer during a series of years.

A — TABLE SHOWING THE INTENSITY OF SOLAR RADIATION AND THE ATMOSPHERIC DEPTH FOR GIVEN ZENITH DISTANCES.

Zenith distance.	Atmospheric depth.	Increment of atmospheric depth.	Maximum intensity.		Observed intensity during a partially cloudy day.	
Deg.	*Relative.*	*Relative.*	*° Fah.*	*° Cent.*	*° Fah.*	*° Cent.*
0	1.000	0.000	67.20	37.33	...	...
1	1.000	0.000	67.19	37.33	...	...
2	1.000	0.000	67.18	37.32	...	...
3	1.001	0.001	67.16	37.31	...	...
4	1.002	0.002	67.14	37.30	...	...
5	1.003	0.003	67.11	37.28	...	...
6	1.005	0.005	67.07	37.26	...	...
7	1.007	0.007	67.02	37.24	...	...
8	1.010	0.010	66.97	37.21	...	...
9	1.013	0.013	66.91	37.17	...	...
10	1.016	0.016	66.84	37.13	...	...
11	1.019	0.019	66.77	37.09	...	...
12	1.023	0.023	66.69	37.05	...	...
13	1.027	0.027	66.60	37.00	...	...
14	1.031	0.031	66.51	36.95	...	...
15	1.036	0.036	66.41	36.89	...	...
16	1.041	0.041	66.30	36.83	...	...
17	1.046	0.046	66.19	36.77	...	...
18	1.051	0.051	66.07	36.70	...	...
19	1.057	0.057	65.94	36.63	...	...
20	1.063	0.063	65.80	36.56	...	...
21	1.070	0.070	65.66	36.48	...	...
22	1.077	0.077	65.51	36.40	...	...
23	1.085	0.085	65.36	36.31	59.5	33.05
24	1.093	0.093	65.20	36.22	58.4	32.44
25	1.102	0.102	65.03	36.13	57.7	32.04

B	Table showing the Intensity of Solar Radiation and the Atmospheric Depth for given Zenith Distances.					
Zenith distance.	Atmospheric depth.	Increment of atmospheric depth.	Maximum intensity.		Observed intensity during a partially cloudy day.	
Deg.	*Relative.*	*Relative.*	*° Fah.*	*° Cent.*	*° Fah.*	*° Cent.*
26	1.111	0.111	64.85	36.03	58.4	32.44
27	1.121	0.121	64.67	35.93	57.5	31.95
28	1.132	0.132	64.48	35.82	57.7	32.05
29	1.141	0.141	64.29	35.72	57.7	32.05
30	1.152	0.152	64.08	35.60	57.8	32.11
31	1.164	0.164	63.87	35.49	56.9	31.61
32	1.176	0.176	63.66	35.36	56.9	31.61
33	1.189	0.189	63.43	35.24	56.7	31.50
34	1.203	0.203	63.20	35.11	57.0	31.66
35	1.217	0.217	62.96	34.98	56.8	31.55
36	1.232	0.232	62.72	34.84	56.4	31.33
37	1.248	0.248	62.47	34.70	56.2	31.22
38	1.265	0.265	62.21	34.56	55.8	31.00
39	1.283	0.283	61.94	34.21	56.1	31.17
40	1.302	0.302	61.67	34.26	55.0	30.55
41	1.322	0.322	61.39	34.11	54.8	30.44
42	1.342	0.342	61.10	33.95	54.8	30.44
43	1.363	0.363	60.81	33.78	54.9	30.50
44	1.384	0.384	60.51	33.62	54.6	30.34
45	1.406	0.406	60.20	33.45	54.7	30.40
46	1.431	0.431	59.88	33.27	54.5	30.28
47	1.457	0.457	59.56	33.09	54.4	30.22
48	1.485	0.485	59.23	32.91	53.4	29.66
49	1.514	0.514	58.89	32.72	53.0	29.44
50	1.545	0.545	58.54	32.52	53.2	29.55

C

TABLE SHOWING THE INTENSITY OF SOLAR RADIATION AND THE ATMOSPHERIC DEPTH FOR GIVEN ZENITH DISTANCES.

Zenith distance.	Atmospheric depth.	Increment of atmospheric depth.	Maximum intensity.		Observed intensity during a partially cloudy day.	
Deg.	*Relative.*	*Relative.*	*° Fah.*	*° Cent.*	*° Fah.*	*° Cent.*
51	1.577	0.577	58.18	32.32	50.7	28.16
52	1.612	0.612	57.81	32.12	50.6	28.11
53	1.648	0.648	57.44	31.91	45.8	25.44
54	1.686	0.686	57.05	31.70	45.4	25.22
55	1.726	0.726	56.66	31.48	44.6	24.77
56	1.769	0.796	56.25	31.25	44.6	24.77
57	1.815	0.815	55.82	31.02	47.0	26.11
58	1.864	0.864	55.39	30.77	48.0	26.66
59	1.916	0.916	54.94	30.52	47.3	26.27
60	1.970	0.970	54.47	30.26	47.4	26.32
61	2.037	1.037	53.99	29.99	46.4	25.77
62	2.098	1.098	53.48	29.72	46.8	26.00
63	2.164	1.164	52.96	29.42	46.8	26.00
64	2.235	1.235	52.41	29.12	46.4	25.77
65	2.312	1.312	51.85	28.81	46.1	25.50
66	2.398	1.398	51.26	28.48	45.0	25.00
67	2.490	1.490	50.63	28.13	42.6	23.66
68	2.591	1.591	49.96	27.76	43.1	23.94
69	2.701	1.701	49.24	27.36	43.2	24.00
70	2.821	1.821	48.43	26.93	42.8	23.77
71	2.952	1.952	47.67	26.46	41.9	23.27
72	3.097	2.097	46.72	25.96	40.4	22.44
73	3.255	2.255	45.72	25.40	33.5	18.61
74	3.428	2.428	44.61	24.79	36.3	20.16
75	3.624	2.624	43.39	24.11	32.4	18.00

TABLE SHOWING THE MAXIMUM INTENSITY OF SOLAR RADIATION ON THE ECLIPTIC.

Date.	*JANUARY.*				*FEBRUARY.*			
	Maximum.		Increment.		Maximum.		Increment.	
	° Fah.	*° Cent.*	*° Fah.*	*° Cent.*	*° Fah.*	*° Cent.*	*° Fah.*	*° Cent*
1	71.94	39.97	4.66	2.59	71.59	39.77	4.31	2.39
2	71.94	39.97	4.66	2.59	71.57	39.76	4.29	2.38
3	71.94	39.97	4.66	2.59	71.54	39.74	4.26	2.36
4	71.93	39.97	4.65	2.59	71.52	39.73	4.24	2.35
5	71.93	39.97	4.65	2.59	71.50	39.72	4.22	2.34
6	71.92	39.96	4.64	2.58	71.47	39.71	4.19	2.33
7	71.92	39.96	4.64	2.58	71.45	39.69	4.17	2.31
8	71.91	39.95	4.63	2.57	71.42	39.68	4.14	2.30
9	71.91	39.95	4.63	2.57	71.40	39.67	4.12	2.29
10	71.90	39.94	4.62	2.56	71.38	39.65	4.10	2.27
11	71.90	39.94	4.62	2.56	71.35	39.64	4.07	2.26
12	71.89	39.93	4.61	2.55	71.32	39.62	4.04	2.24
13	71.88	39.93	4.60	2.55	71.29	39.60	4.01	2.22
14	71.87	39.92	4.59	2.54	71.27	39.59	3.99	2.21
15	71.86	39.92	4.58	2.54	71.24	39.58	3.96	2.20
16	71.85	39.91	4.57	2.53	71.20	39.56	3.92	2.18
17	71.84	39.91	4.56	2.53	71.17	39.54	3.89	2.16
18	71.82	39.90	4.54	2.52	71.14	39.52	3.86	2.14
19	71.81	39.90	4.53	2.52	71.11	39.50	3.83	2.12
20	71.80	39.89	4.52	2.51	71.08	39.49	3.80	2.11
21	71.78	39.88	4.50	2.50	71.05	39.47	3.77	2.09
22	71.77	39.87	4.49	2.49	71.02	39.45	3.74	2.07
23	71.76	39.87	4.48	2.48	70.98	39.43	3.70	2.05
24	71.74	39.86	4.46	2.47	70.95	39.42	3.67	2.04
25	71.72	39.84	4.44	2.46	70.92	39.40	3.64	2.02
26	71.70	39.83	4.42	2.45	70.88	39.38	3.60	2.00
27	71.68	39.82	4.40	2.44	70.85	39.36	3.57	1.98
28	71.67	39.81	4.39	2.43	70.82	39.34	3.54	1.96
29	71.65	39.80	4.37	2.42				
30	71.63	39.79	4.35	2.41				
31	71.61	39.78	4.33	2.40				

TABLE SHOWING THE MAXIMUM INTENSITY OF SOLAR RADIATION ON THE ECLIPTIC.

Date.	*MARCH.*				*APRIL.*			
	Maximum.		Increment.		Maximum.		Increment.	
	° Fah.	*° Cent.*	*° Fah.*	*° Cent.*	*° Fah.*	*° Cent.*	*° Fah.*	*° Cent.*
1	70.79	39.33	3.51	1.95	69.60	38.67	2.32	1.29
2	70.75	39.31	3.47	1.93	69.56	38.64	2.38	1.26
3	70.72	39.29	3.44	1.91	69.52	38.62	2.24	1.24
4	70.68	39.27	3.40	1.89	69.48	38.60	2.20	1.22
5	70.65	39.25	3.37	1.87	69.44	38.58	2.16	1.20
6	70.61	39.23	3.33	1.85	69.40	38.56	2.12	1.18
7	70.58	39.21	3.30	1.83	69.36	38.53	2.08	1.15
8	70.54	39.19	3.26	1.81	69.32	38.51	2.04	1.13
9	70.50	39.17	3.22	1.79	69.28	38.49	2.00	1.11
10	70.46	39.14	3.18	1.76	69.24	38.47	1.96	1.09
11	70.42	39.12	3.14	1.74	69.20	38.44	1.92	1.06
12	70.38	39.10	3.10	1.72	69.16	38.42	1.88	1.04
13	70.35	39.08	3.07	1.70	69.13	38.40	1.85	1.02
14	70.31	39.06	3.03	1.68	69.09	38.38	1.81	1.00
15	70.27	39.04	2.99	1.66	69.05	38.36	1.77	0.98
16	70.23	39.02	2.95	1.64	69.01	38.34	1.73	0.96
17	70.19	38.99	2.91	1.61	68.97	38.32	1.69	0.94
18	70.15	38.97	2.87	1.59	68.93	38.29	1.65	0.91
19	70.12	38.95	2.84	1.57	68.89	38.27	1.61	0.89
20	70.08	38.93	2.80	1.55	68.85	38.25	1.57	0.87
21	70.04	38.91	2.76	1.53	68.81	38.23	1.53	0.85
22	70.00	38.89	2.72	1.51	68.78	38.21	1.50	0.83
23	69.96	38.87	2.68	1.49	68.74	38.19	1.46	0.81
24	69.92	38.84	2.64	1.46	68.70	38.17	1.42	0.79
25	69.88	38.82	2.60	1.44	68.66	38.14	1.38	0.76
26	69.84	38.80	2.56	1.42	68.63	38.12	1.35	0.74
27	69.80	38.78	2.52	1.40	68.59	38.10	1.31	0.72
28	69.76	38.75	2.48	1.37	68.55	38.08	1.27	0.70
29	69.72	38.73	2.44	1.35	68.52	38.06	1.24	0.68
30	69.68	38.71	2.40	1.33	68.48	38.04	1.20	0.66
31	69.64	38.69	2.36	1.31				

TABLE SHOWING THE MAXIMUM INTENSITY OF SOLAR RADIATION ON THE ECLIPTIC.

Date.	*MAY.*				*JUNE.*			
	Maximum.		Increment.		Maximum.		Increment.	
	° *Fah.*	° *Cent.*	° *Fah.*	° *Cent.*	° *Fah.*	° *Cent.*	° *Fah.*	° *Cent.*
1	68.45	38.03	1.17	0.65	67.58	37.54	0.30	0.16
2	68.41	38.01	1.13	0.63	67.56	37.53	0.28	0.15
3	68.38	37.99	1.10	0.61	67.54	37.52	0.26	0.14
4	68.35	37.97	1.07	0.59	67.52	37.51	0.24	0.13
5	68.32	37.95	1.04	0.57	67.51	37.50	0.23	0.12
6	68.28	37.93	1.00	0.55	67.49	37.49	0.21	0.11
7	68.25	37.92	0.97	0.54	67.47	37.48	0.19	0.10
8	68.22	37.90	0.94	0.52	67.46	37.48	0.18	0.10
9	68.19	37.88	0.91	0.50	67.44	37.47	0.16	0.09
10	68.16	37.87	0.88	0.49	67.43	37.46	0.15	0.08
11	68.13	37.85	0.85	0.47	67.42	37.45	0.14	0.07
12	68.10	37.83	0.82	0.45	67.40	37.44	0.12	0.06
13	68.06	37.81	0.78	0.43	67.39	37.44	0.11	0.06
14	68.03	37.79	0.75	0.41	67.38	37.43	0.10	0.05
15	68.00	37.78	0.72	0.40	67.37	37.43	0.09	0.05
16	67.97	37.76	0.69	0.38	67.36	37.42	0.08	0.04
17	67.94	37.74	0.66	0.36	67.35	37.42	0.07	0.04
18	67.91	37.73	0.63	0.35	67.34	37.41	0.06	0.03
19	67.89	37.72	0.61	0.34	67.33	37.40	0.05	0.02
20	67.86	37.70	0.58	0.32	67.32	37.40	0.04	0.02
21	67.84	37.69	0.56	0.31	67.32	37.40	0.04	0.02
22	67.81	37.67	0.53	0.29	67.31	37.39	0.03	0.01
23	67.79	37.66	0.51	0.28	67.30	37.39	0.02	0.01
24	67.77	37.65	0.49	0.27	67.30	37.39	0.02	0.01
25	67.75	37.64	0.47	0.26	67.29	37.38	0.01	0.00
26	67.72	37.62	0.44	0.24	67.29	37.38	0.01	0.00
27	67.70	37.61	0.42	0.23	67.28	37.38	0.00	0.00
28	67.67	37.59	0.39	0.21	67.28	37.38	0.00	0.00
29	67.65	37.58	0.37	0.20	67.28	37.38	0.00	0.00
30	67.63	37.57	0.35	0.19	67.28	37.38	0.00	0.00
31	67.60	37.55	0.32	0.17				

Table showing the Maximum Intensity of Solar Radiation on the Ecliptic.

Date.	*JULY.*				*AUGUST.*			
	Maximum.		Increment.		Maximum.		Increment.	
	° Fah.	*° Cent.*	*° Fah.*	*° Cent.*	*° Fah.*	*° Cent.*	*° Fah.*	*° Cent.*
1	67.28	37.38	0.00	0.00	67.58	37.54	0.30	0.16
2	67.28	37.38	0.00	0.00	67.60	37.55	0.32	0.17
3	67.28	37.38	0.00	0.00	67.63	37.57	0.35	0.19
4	67.28	37.38	0.00	0.00	67.65	37.58	0.37	0.20
5	67.28	37.38	0.00	0.00	67.67	37.59	0.39	0.21
6	67.28	37.38	0.00	0.00	67.70	37.61	0.42	0.23
7	67.29	37.38	0.01	0.00	67.72	37.62	0.44	0.24
8	67.29	37.38	0.01	0.00	67.75	37.64	0.47	0.26
9	67.30	37.39	0.02	0.01	67.77	37.65	0.49	0.27
10	67.30	37.39	0.02	0.01	67.79	37.66	0.51	0.28
11	67.31	37.39	0.03	0.01	67.81	37.67	0.53	0.29
12	67.32	37.40	0.04	0.02	67.84	37.69	0.56	0.31
13	67.32	37.40	0.04	0.02	67.86	37.70	0.58	0.32
14	67.33	37.41	0.05	0.03	67.89	37.72	0.61	0.34
15	67.34	37.41	0.06	0.03	67.91	37.73	0.63	0.35
16	67.35	37.42	0.07	0.04	67.94	37.74	0.66	0.36
17	67.36	37.42	0.08	0.04	67.97	37.76	0.69	0.38
18	67.37	37.43	0.09	0.05	68.00	37.78	0.72	0.40
19	67.38	37.43	0.10	0.05	68.03	37.79	0.75	0.41
20	67.39	37.44	0.11	0.06	68.06	37.81	0.78	0.43
21	67.40	37.44	0.12	0.06	68.10	37.83	0.82	0.45
22	67.42	37.45	0.14	0.07	68.13	37.85	0.85	0.47
23	67.43	37.46	0.15	0.08	68.16	37.87	0.88	0.49
24	67.44	37.47	0.16	0.09	68.19	37.88	0.91	0.50
25	67.46	37.48	0.18	0.10	68.22	37.90	0.94	0.52
26	67.47	37.48	0.19	0.10	68.25	37.92	0.97	0.54
27	67.49	37.49	0.21	0.11	68.28	37.93	1.00	0.55
28	67.51	37.50	0.23	0.12	68.32	37.95	1.04	0.57
29	67.52	37.51	0.24	0.13	68.35	37.97	1.07	0.59
30	67.54	37.52	0.26	0.14	68.38	37.99	1.10	0.61
31	67.56	37.53	0.28	0.15	68.41	38.01	1.13	0.63

TABLE SHOWING THE MAXIMUM INTENSITY OF SOLAR RADIATION ON THE ECLIPTIC.

Date.	*SEPTEMBER.*				*OCTOBER.*			
	Maximum.		Increment.		Maximum.		Increment.	
	° *Fah.*	° *Cent.*	° *Fah.*	° *Cent.*	° *Fah.*	° *Cent.*	° *Fah.*	° *Cent.*
1	68.45	38.03	1.17	0.65	69.60	38.67	2.32	1.29
2	68.48	38.04	1.20	0.66	69.64	38.69	2.36	1.31
3	68.52	38.06	1.24	0.68	69.68	38.71	2.40	1.33
4	68.55	38.08	1.27	0.70	69.72	38.73	2.44	1.35
5	68.59	38.10	1.31	0.72	69.76	38.75	2.48	1.37
6	68.63	38.12	1.35	0.74	69.80	38.78	2.52	1.40
7	68.66	38.14	1.38	0.76	69.84	38.80	2.56	1.42
8	68.70	38.17	1.42	0.79	69.88	38.82	2.60	1.44
9	68.74	38.19	1.46	0.81	69.92	38.84	2.64	1.46
10	68.78	38.21	1.50	0.83	69.96	38.87	2.68	1.49
11	68.81	38.23	1.53	0.85	70.00	38.89	2.72	1.51
12	68.85	38.25	1.57	0.87	70.04	38.91	2.76	1.53
13	68.89	38.27	1.61	0.89	70.08	38.93	2.80	1.55
14	68.93	38.29	1.65	0.91	70.12	38.95	2.84	1.57
15	68.97	38.32	1.69	0.94	70.15	38.97	2.87	1.59
16	69.01	38.34	1.73	0.96	70.19	38.99	2.91	1.61
17	69.05	38.36	1.77	0.98	70.23	39.02	2.95	1.64
18	69.09	38.38	1.81	1.00	70.27	39.04	2.99	1.66
19	69.13	38.40	1.85	1.02	70.31	39.06	3.03	1.68
20	69.16	38.42	1.88	1.04	70.35	39.08	3.07	1.70
21	69.20	38.44	1.92	1.06	70.38	39.10	3.10	1.72
22	69.24	38.47	1.96	1.09	70.42	39.12	3.14	1.74
23	69.28	38.49	2.00	1.11	70.46	39.14	3.18	1.76
24	69.32	38.51	2.04	1.13	70.50	39.17	3.22	1.79
25	69.36	38.53	2.08	1.15	70.54	39.19	3.26	1.81
26	69.40	38.56	2.12	1.18	70.58	39.21	3.30	1.83
27	69.44	38.58	2.16	1.20	70.61	39.23	3.33	1.85
28	69.48	38.60	2.20	1.22	70.65	39.25	3.37	1.87
29	69.52	38.62	2.24	1.24	70.68	39.27	3.40	1.89
30	69.56	38.64	2.28	1.26	70.72	39.29	3.44	1.91
31	...	...	...	...	70.75	39.31	3.47	1.93

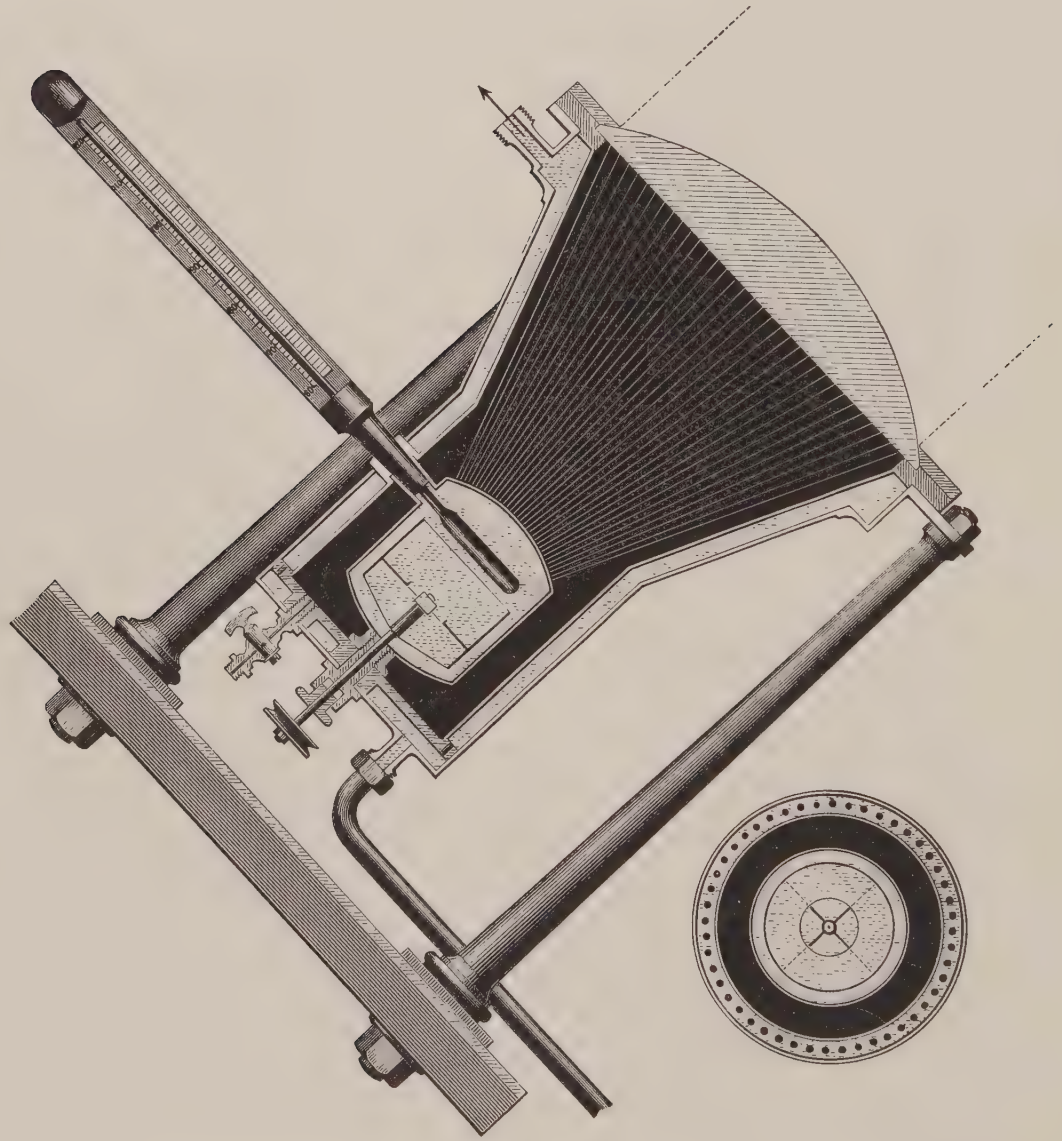
TABLE SHOWING THE MAXIMUM INTENSITY OF SOLAR RADIATION ON THE ECLIPTIC.

Date.	*NOVEMBER.*				*DECEMBER.*			
	Maximum.		Increment.		Maximum.		Increment.	
	° Fah.	*° Cent.*	*° Fah.*	*° Cent.*	*° Fah.*	*° Cent.*	*° Fah.*	*° Cent.*
1	70.79	39.33	3.51	1.95	71.63	39.79	4.25	2.41
2	70.82	39.34	3.54	1.96	71.65	39.80	4.37	2.42
3	70.85	39.36	3.57	1.98	71.67	39.81	4.39	2.43
4	70.88	39.38	3.60	2.00	71.68	39.82	4.40	2.44
5	70.92	39.40	3.64	2.02	71.70	39.83	4.42	2.45
6	70.95	39.42	3.67	2.04	71.72	39.84	4.44	2.46
7	70.98	39.43	3.70	2.05	71.74	39.86	4.46	2.47
8	71.02	39.45	3.74	2.07	71.76	39.87	4.48	2.48
9	71.05	39.47	3.77	2.09	71.77	39.87	4.49	2.49
10	71.08	39.49	3.80	2.11	71.78	39.88	4.50	2.50
11	71.11	39.50	3.83	2.12	71.80	39.89	4.52	2.51
12	71.14	39.52	3.86	2.14	71.81	39.90	4.53	2.52
13	71.17	39.54	3.89	2.16	71.82	39.90	4.54	2.52
14	71.20	39.56	3.92	2.18	71.84	39.91	4.56	2.53
15	71.24	39.58	3.96	2.20	71.85	39.91	4.57	2.53
16	71.27	39.59	3.99	2.21	71.86	39.92	4.58	2.54
17	71.29	39.60	4.01	2.22	71.87	39.92	4.59	2.54
18	71.32	39.62	4.04	2.24	71.88	39.93	4.60	2.55
19	71.35	39.64	4.07	2.26	71.89	39.93	4.61	2.55
20	71.38	39.65	4.10	2.27	71.90	39.94	4.62	2.56
21	71.40	39.67	4.12	2.29	71.90	39.94	4.62	2.56
22	71.42	39.68	4.14	2.30	71.91	39.95	4.63	2.57
23	71.45	39.69	4.17	2.31	71.91	39.95	4.63	2.57
24	71.47	39.71	4.19	2.33	71.92	39.96	4.64	2.58
25	71.50	39.72	4.22	2.34	71.92	39.96	4.64	2.58
26	71.52	39.73	4.24	2.35	71.93	39.97	4.65	2.59
27	71.54	39.74	4.26	2.36	71.93	39.97	4.65	2.59
28	71.57	39.76	4.29	2.38	71.94	39.97	4.66	2.59
29	71.59	39.77	4.31	2.39	71.94	39.97	4.66	2.59
30	71.61	39.78	4.33	2.40	71.94	39.97	4.66	2.59
31	...	...	...	...	71.94	39.97	4.66	2.59

SOLAR CALORIMETER.

DESIGNED BY JOHN ERICSSON.

MANUFACTURED AT NEW YORK, 1870.



THE SOLAR CALORIMETER.

The mechanical energy developed by solar radiation cannot be accurately determined unless we possess means of ascertaining (1) the energy actually called forth by the sun's radiant heat at the surface of the earth, and (2) the energy lost during the passage of the rays through our atmosphere. The illustration on the opposite page represents a *solar calorimeter*, an instrument constructed for measuring the energy actually developed near the earth's surface.

Sir John Herschel and M. Pouillet conceived the idea, nearly at the same time, of measuring the energy of solar radiation by exposing a given quantity of water, presenting a given area, to the sun's rays. Having ascertained the elevation of temperature of the water acquired in a given time, and added the energy supposed to be lost by atmospheric absorption, together with the loss consequent on the dispersion of the rays, they computed the total dynamic energy developed by the sun. Herschel employed a small stationary open vessel, which he termed actinometer; while Pouillet resorted to a close movable vessel, the well-known "pyrheliometer." This instrument having been described in nearly all recent works on solar energy, and accurately delineated in Pouillet's "Éléments de Physique" (Tome II., Paris, 1856), it will only be necessary to remind the reader that the vessel exposed to the sun, composed of polished silver, contains 100 grammes of water. The diameter is 1 decimetre and the depth 15 millimetres, the top exposed to the sun's rays being coated with lamp-black. The radical defect of Pouillet's instrument is that it cannot be used during winter when the thermometer

is below the freezing point, as warm water would have to be used, in which case the loss of heat by radiation and convection would be so great as to render the task futile of accurately measuring the force of solar radiation. This defect of Pouillet's method is the more serious as the heat of the sun is most intense during the winter solstice for given zenith distances, on account of the diminished distance between the sun and the earth, and because the sky is generally clearer on a cold winter's day than during the heat of summer when the air is charged with vapor.

The loss of heat by radiation, in the pyrheliometer; loss of heat by convection, accelerated by currents of air; the absence of adequate means for circulating the fluid contained within the heater; the rude method of keeping the instrument perpendicular to the sun with the hand, not to mention the disturbing influence of respiration and the radiation from the operator's body, are self-evident defects. Nor can we pass unnoticed the want of any direct means of ascertaining the depth of the atmosphere through which the radiant heat passes at the moment of measuring its energy. I need scarcely point out that computations based on *latitude*, *date*, and *exact time* are too complex and tedious for investigations in which the principal element, the depth of the atmosphere, is continually changing.

It will be well to state that the solar calorimeter, and all my instruments constructed for investigating the mechanical properties of solar heat, are attached to a vibrating table applied within a revolving observatory, supported on horizontal journals and provided with a declination movement and a graduated arc. Consequently, the sun's zenith distance may

at all times be ascertained by mere inspection, a very great convenience in an investigation which at every instant is dependent on the changing depth of the atmosphere through which the solar rays pass.

The result of my observations with the solar calorimeter shows that on March 7, 1871, the dynamic energy developed by solar radiation was greater than at any other time during a period of seven years. Making proper allowance for zenith distance and the earth's position in its orbit, it was found that on the day mentioned the energy developed on the ecliptic amounted to 5.64 units on an area of one square foot in one minute. The absorptive power of the terrestrial atmosphere, determined by my observations, being 0.207 in the vertical line, it will be seen that the dynamic energy developed on one square foot of surface at the boundary of the atmosphere is 7.11 units per minute. The dispersion of the rays being in the ratio of 45,400 to 1 on the day mentioned, it will be found that, agreeably to my calorimetric observation, the energy of solar emission amounts to 322,794 units per minute on one square foot of the photosphere.

INSTRUMENT FOR MEASURING THE ACTUAL INTENSITY OF SOLAR RADIATION.

The annexed illustration represents a vertical section through the centre line of the instrument. The leading feature of the device is that of applying a hollow revolving sphere (composed of very thin copper) within an exhausted cylindrical vessel. This revolving sphere, coated with lamp-black inside and outside, is exposed to the sun's rays admitted through a thin crystal covering the open end of the exhausted vessel, the

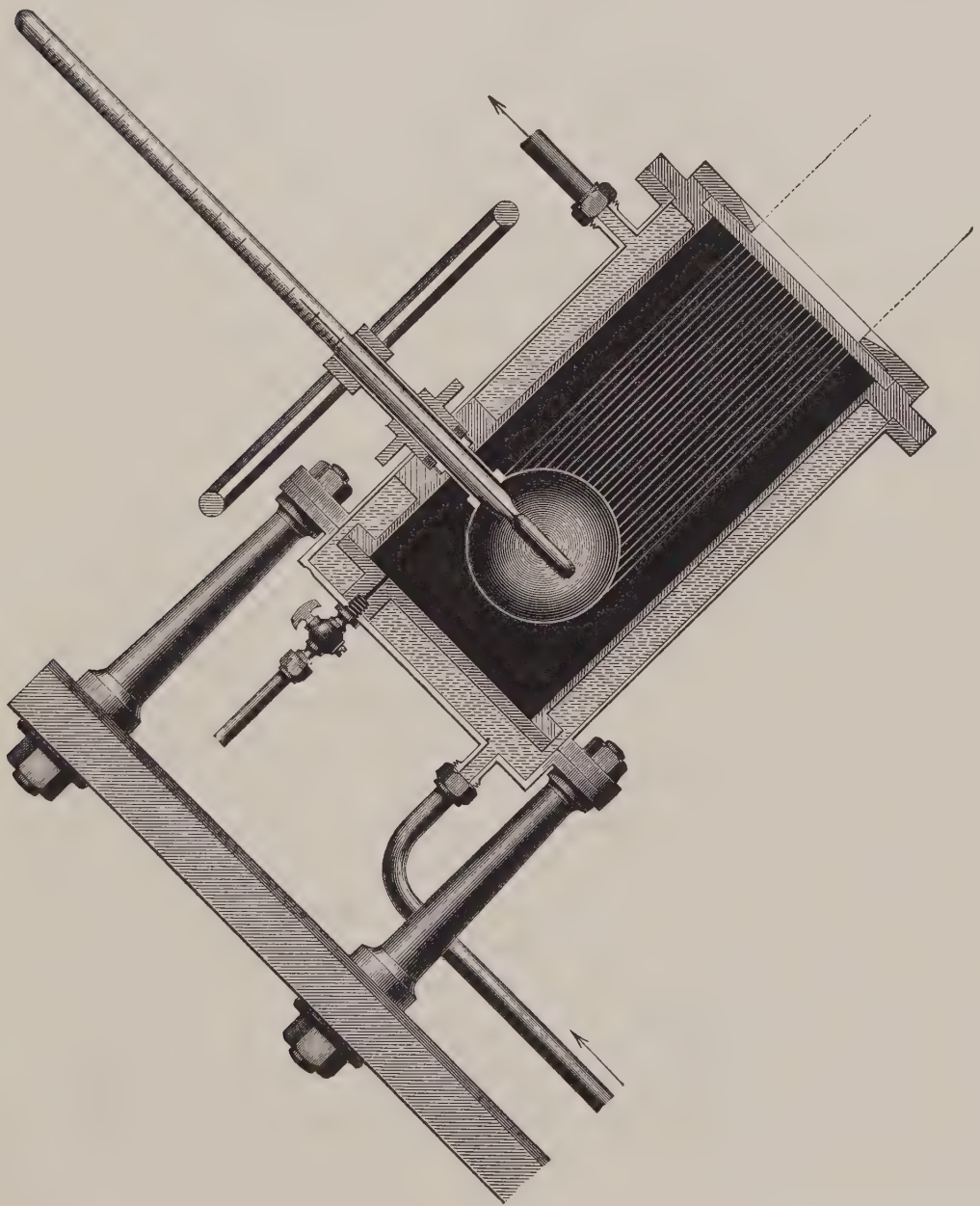
diameter of the crystal being equal to that of the sphere. The exhausted cylindrical vessel, it will be seen by inspecting the illustration, is surrounded by an external casing, water of a given temperature being circulated through the intervening space. The sphere is caused to revolve by means of a small hand-wheel attached to a hollow stem connected with the sphere; the said stem turning in an air-tight stuffing-box applied on the upper side of the exhausted vessel. A thermometer is inserted through the hollow stem, the bulb, coated with lamp-black, occupying a central position within the sphere. Obviously the thermometer participates in the rotary motion of the sphere when turned by the hand-wheel. The instrument is supported on columns secured to a table provided with parallactic movement for the purpose of pointing the axis of the exhausted cylindrical vessel towards the solar centre. The water circulated through the external casing of the instrument is maintained at a constant temperature of 60° F., a vacuum being kept up within the internal vessel. As the thermometer does not fit air-tight in the hollow stem, it will be evident that the pressure of the air within the revolving sphere will at all times balance the external atmospheric pressure. Let us now institute a comparison between the instrument described and the ordinary thermometer.

The convex area of the revolving sphere being four times greater than the area of its great circle, the latter being equal to the area of the pencil of rays admitted through the crystal, it will be evident that the refrigerating surface of the sphere is *four* times greater than the sectional area of the solar rays which supply the radiant heat. Accordingly, if the surrounding cylindrical vessel be permitted to radiate freely towards

INSTRUMENT

FOR MEASURING THE ACTUAL INTENSITY OF THE SUN'S RAYS.

DESIGNED BY JOHN ERICSSON. MANUFACTURED AT NEW YORK 1872.



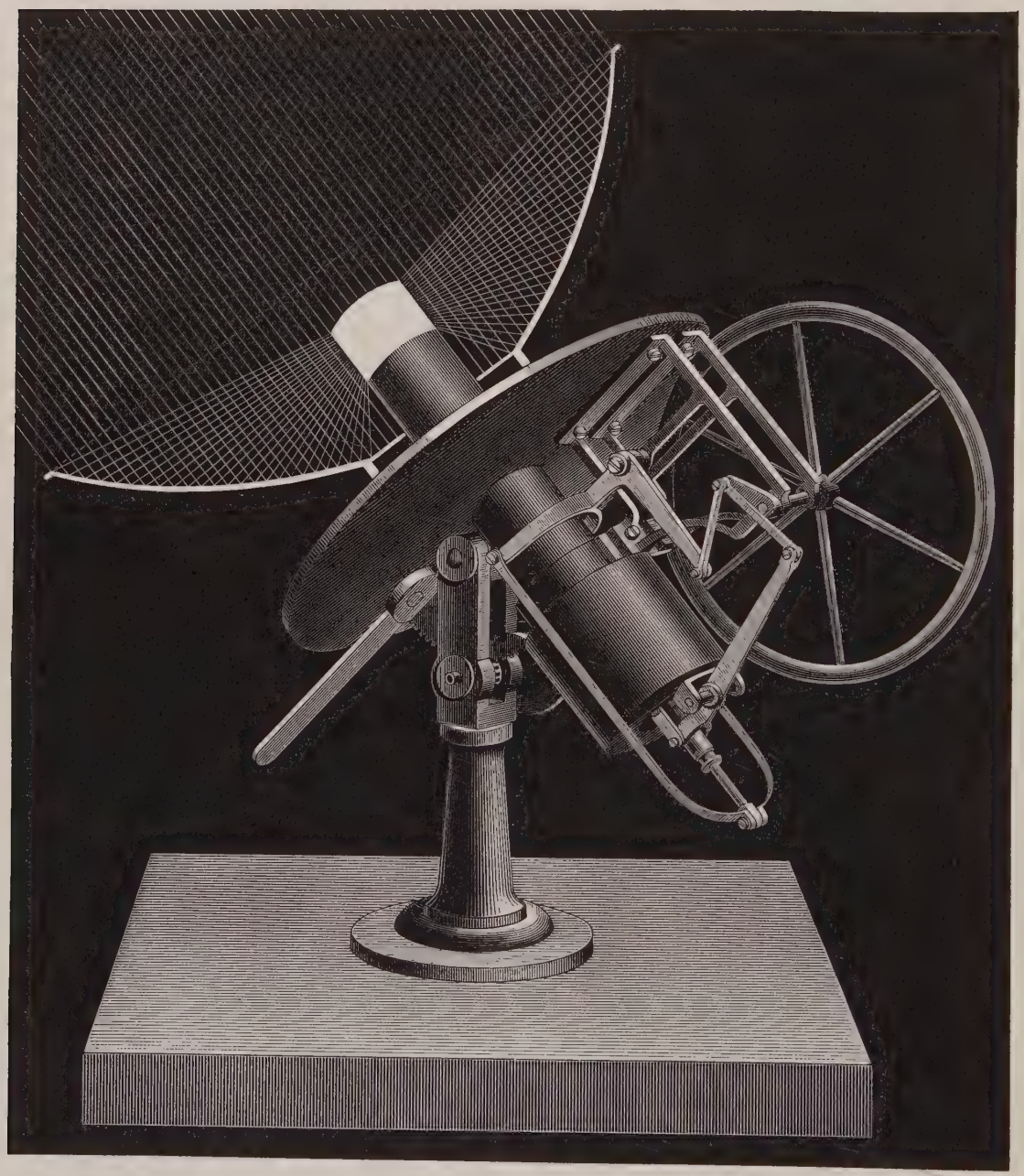
the centre, the temperature retained by the revolving sphere thus exposed to cold radiation from all points will be only one-fourth of the temperature capable of being imparted by the pencil of rays to the face of a flat disc composed of some non-conducting substance. It may be stated, in further explanation of the foregoing demonstration, that, since the surrounding exhausted vessel is maintained at a constant temperature of 60° F., it will radiate heat of that energy towards the sphere. An exchange will consequently take place which will prevent maximum temperature being attained by the sphere unless the radiant energy transmitted by the solar rays entering the instrument be *four* times greater for equal area than the radiant energy of the heat-rays projected by the sphere towards the cold enclosure. It follows from this important proposition that the temperature acquired by the revolving sphere represents only one-fourth of the intensity of the radiant energy actually passing through the crystal of the exhausted cylindrical vessel. It will be readily perceived that the temperature of the air within the revolving sphere correctly represents the temperature of the metal composing the same; also, that the metal itself, owing to its almost perfect conductivity, will become uniformly heated all over. The inserted thermometer, therefore, will show the temperature of the revolving sphere sufficiently near for the object in view. As already demonstrated, only one-fourth of the radiant heat entering through the crystal is retained by the sphere; hence the thermometer will indicate only one-fourth of the actual intensity of the sun's rays. Accordingly, if we multiply the indication of the thermometer within the revolving sphere by 4, we ascertain the true solar intensity, less the

heat absorbed by the crystal covering the exhausted vessel. The result of careful observation has proved the soundness of the foregoing reasoning and demonstration. The concluding investigation, instituted when the zenith distance was 30 deg. 50 min., established the fact that, while the standard actinometer indicated a solar intensity of 54°.57 F., the thermometer within the revolving sphere indicated a differential temperature of 13°.3 F. According to our theory it should have indicated $\frac{54.57}{4} = 13°.64$ F., thus showing a deficiency of 0°.34. If, however, a correction be introduced adding the proportion of heat absorbed by the crystal—viz., 0.06—the stated deficiency of temperature will be more than balanced. This apparent inaccuracy is occasioned by the radiation of the crystal towards the sphere, and by the diminution of the radiating surface of the surrounding vessel at the point where the crystal is inserted. The last-mentioned source of error may be easily ascertained, as it depends on the solid angle formed by straight lines drawn from the circumference of the crystal to the centre of the sphere. The deficiency of radiating surface ascertained by that process amounts to 0.012. Proper allowance having been made on account of these sources of error, it was found during the concluding investigation referred to that the temperature retained by the sphere exposed to the solar heat is exactly *one-fourth* of the temperature imparted and retained by the bulb of an actinometer simultaneously exposed to the sun. It is important to observe that the difference between the intensity of the radiant heat of the sun and the temperature of the metal composing the sphere was 54°.57 — 13°.64 = 40°.93 F. during the investigation; while the

SOLAR ENGINE.

OPERATED BY THE INTERVENTION OF ATMOSPHERIC AIR.

DESIGNED BY JOHN ERICSSON. CONSTRUCTED AT NEW YORK, 1872.



temperature of the bulb of the actinometer exposed to the sun, at the same time, balanced the intensity of the solar heat. Regarding the *actual intensity* of solar radiation, no further demonstration is needed to show that the temperature indicated by the thermometer within the revolving sphere, multiplied by 4, determines the *true* energy of the sun's radiant heat at the surface of the earth; not, however, including the energy lost by atmospheric absorption.

THE SOLAR ENGINE.

The accompanying illustration represents a solar engine operated by the intervention of atmospheric air, a plan which I prefer for all purposes not calling for great power. This model engine runs at a steady rate of 420 turns per minute when the sun is in the zenith and the sky is clear. For large power I have found it most advantageous to operate the engine by steam, since by the intervention of water it is easy to concentrate the energy developed by any number of reflectors or other contrivances capable of augmenting the temperature produced by direct solar radiation.

While conducting the investigations relating to the intensity of solar radiation, I also carried out a series of very extensive experiments with reflectors of a peculiar form, in order to ascertain what amount of power may be obtained for mechanical purposes, which prove that the sun's radiant heat, on an average, during nine hours a day, for all latitudes between the equator and 45 deg., develops fully 3.5 units of heat per minute for each square foot of area presented perpendicularly to the sun's rays. A unit of heat being equivalent to 772 foot-pounds, it will be perceived that, theoretically, a dynamic

energy of 2,702 foot-pounds is transmitted by the radiant heat per minute for each square foot; hence 270,200 foot-pounds for an area of 10 ft. square. If we divide this sum by the adopted standard of 33,000, we ascertain that 100 square feet of surface exposed to the solar rays develop continuously 8.2 horse-power during nine hours a day, within the limits of latitude before mentioned. But engineers are well aware that the whole dynamic energy of heat cannot be utilized in practice by any engine or mechanical combination whatever, nor at all approached; hence I have assumed, in order not to overrate the capability of the new system, that a solar engine of 1 horse-power demands the concentration of solar heat from an area of 10 ft. square. On this basis I will now proceed to show that those regions of the earth which suffer from an excess of solar heat will ultimately derive benefits resulting from an unlimited command of motive power which will, to a great extent, compensate for evils hitherto supposed not to be counterbalanced by any good. The isolated districts of the earth's surface suffering from an excess of solar heat being very numerous, our space only admits of a glance at the sunburnt continents. An examination of the extent of these will show that the field for the solar engine, even with the proposed restriction, is incalculably great. There is a rainless region extending from the northwest coast of Africa to Mongolia, 9,000 miles in length and nearly 1,000 miles wide. Besides the Northern African deserts, this region includes the southern coast of the Mediterranean east of the Gulf of Cabes, Upper Egypt, the eastern and part of the western coast of the Red Sea, part of Syria, the eastern part of the countries watered by the Euphrates and Tigris, Eastern Arabia, the greater part

of Persia, the extreme western part of China, Tibet, and, lastly, Mongolia. In the western hemisphere, Lower California, the table-land of Mexico and Guatemala, and the west coast of South America for a distance of more than 2,000 miles, suffer from continuous intense radiant heat.

Computations of the solar energy wasted on the vast areas thus specified would present an amount of dynamic force almost beyond conception. Let us, therefore, merely estimate the mechanical force that would result from utilizing the solar heat on a strip of land, a single mile in width, along the rainless western coast of America; the southern coast of the Mediterranean before referred to; both sides of the alluvial plain of the Nile in Upper Egypt; both sides of the Euphrates and Tigris for a distance of four hundred miles above the Persian Gulf; and, finally, a strip one mile wide along the rainless portions of the shores of the Red Sea, before pointed out. The aggregate length of these strips of land, selected on account of being accessible by water communication, far exceeds eight thousand miles. Adopting this length and a width of one mile as a basis for computation, it will be seen that the assumed narrow belt of the sun-burnt continents covers 223,000 millions of square feet. Dividing this by the area necessary to produce 1 horse-power, we learn that 22,300,000 solar engines, each of 100 horse-power, could be kept in constant operation, nine hours a day, by utilizing only that heat which is now wasted on a very small fraction of the land extending along some of the water-fronts of the sun-burnt regions of the earth.

It will be said that these extravagant figures are devoid of practical significance. Due consideration, however, cannot fail to convince us that the gradual exhaustion of the coal-fields

will inevitably cause great changes in regard to international relations in favor of those countries which are in possession of continuous sun-power. Upper Egypt, for instance, will, in the course of time, derive signal advantage and attain a high political position on account of her perpetual sunshine, and the consequent command of unlimited motive force. The time will come when Europe must stop her mills for the want of coal. Upper Egypt, then, with her never-ceasing sun-power, will invite the European manufacturer to remove his machinery and erect his mills on the firm ground along the sides of the alluvial plain of the Nile, where sufficient power can be obtained to enable him to run more spindles than a hundred such cities as Manchester.

J. Ericsson.

New York, June 23, 1876.

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